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CLAIMS

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[Claim(s)]

[Claim 1]A n type nitride semiconductor layer field where n side contact layer, a n side clad layer, and the n side light guide layer were laminated on a substrate.

A p type nitride semiconductor layer field where an active layer which consists of nitride semiconductors, the p side light guide layer and a p side clad layer, and p side contact layer were laminated.

Are the above the nitride semiconductor device which it had, and said p side clad

layer, It has thickness of 100A or less at not less than 10A, and a presentation differs from the 1st layer that consists of a nitride semiconductor which does not contain aluminum, and this 1st layer, and it has thickness of 100A or less at not less than 10A, and the 2nd layer that consists of a nitride semiconductor containing aluminum is characterized by being the laminated superlattice layers.

[Claim 2]The nitride semiconductor device according to claim 1 by which a p type impurity was doped by either [ at least ] said 1st layer or said 2nd layer.

[Claim 3]The nitride semiconductor device according to claim 2 from which concentration of a p type impurity doped by said 1st layer and said 2nd layer differs mutually.

[Claim 4]The nitride semiconductor device according to claim 2 or 3 which bandgap energy of said 1st layer and said 2nd layer differed mutually, and enlarged impurity concentration of a layer with large bandgap energy.

[Claim 5]A n type nitride semiconductor layer field where n side contact layer, a n side clad layer, and the n side light guide layer were laminated on a substrate, It is a nitride semiconductor device which has the p type nitride semiconductor layer field where an active layer which consists of nitride semiconductors, the p

side light guide layer and a p side clad layer, and p side contact layer were laminated, Among said p side clad layer and said n side clad layer, at least one.

The 1st layer that consists of a nitride semiconductor which has thickness of 100A or less at not less than 10A, and does not contain aluminum, A nitride semiconductor device, wherein the 2nd layer that consists of a nitride semiconductor which a presentation differs from this 1st layer, and has thickness of 100A or less at not less than 10A, and contains aluminum is the laminated superlattice layers.

[Claim 6]A nitride semiconductor device of Claim 5 by which said p side clad layers are said superlattice layers, and a p type impurity was doped by either [ at least ] said 1st layer or said 2nd layer.

[Claim 7]The nitride semiconductor device according to claim 6 from which concentration of a p type impurity doped by said 1st layer and said 2nd layer differs mutually.

[Claim 8]The nitride semiconductor device according to claim 7 which bandgap energy of said 1st layer and said 2nd layer differed mutually, and enlarged impurity concentration of a layer with large bandgap energy.

[Claim 9]A nitride semiconductor device of Claim 5 by which said n side clad

layers are said superlattice layers, and a n type impurity was doped by either [ at least ] said 1st layer or said 2nd layer.

[Claim 10]The nitride semiconductor device according to claim 9 from which concentration of a n type impurity doped by said 1st layer and said 2nd layer differs mutually.

[Claim 11]The nitride semiconductor device according to claim 10 which bandgap energy of said 1st layer and said 2nd layer differed mutually, and enlarged impurity concentration of a layer with large bandgap energy.

[Claim 12]The nitride semiconductor device according to claim 1 to 11 in which said 2nd layer is a nitride semiconductor expressed with formula  $\text{aluminum}_Y\text{Ga}_{1-Y}\text{N}$  (however,  $0 < Y \leq 1$ ).

[Claim 13]Said 1st layer consists of a nitride semiconductor expressed with formula  $\text{In}_X\text{Ga}_{1-X}\text{N}$  ( $0 \leq X \leq 1$ ) in said superlattice layers, And the nitride semiconductor device according to claim 12 which said 2nd layer becomes from a nitride semiconductor expressed with formula  $\text{aluminum}_Y\text{Ga}_{1-Y}\text{N}$  (however,  $0 < Y \leq 1$ ).

[Claim 14]Said 1st layer consists of a nitride semiconductor expressed with formula  $\text{In}_X\text{Ga}_{1-X}\text{N}$  ( $0 \leq X < 1$ ) in said superlattice layers, And the nitride



semiconductor device according to claim 13 which said 2nd layer becomes from a nitride semiconductor expressed with formula  $\text{Al}_Y\text{Ga}_{1-Y}\text{N}$  (however,  $0 < Y < 1$ ).

[Claim 15] A nitride semiconductor device given in any 1 clause of the Claims 1-14 which said 1st layer and said 2nd layer become from a nitride semiconductor which has thickness of 70Å or less, respectively.

[Claim 16] A nitride semiconductor device given in any 1 clause of the Claims 1-15 whose thickness of said p side contact layer is 500Å or less.

[Claim 17] The nitride semiconductor device according to claim 16 whose thickness of said p side contact layer is 300Å or less and not less than 10Å further.

[Claim 18] A n type nitride semiconductor layer field where n side contact layer, a n side clad layer, and the n side light guide layer were laminated on a substrate, It is a nitride semiconductor device which has the p type nitride semiconductor layer field where an active layer which consists of nitride semiconductors, the p side light guide layer and a p side clad layer, and p side contact layer were laminated, The 1st layer that consists of a nitride semiconductor with which said n side clad layer has thickness of 100Å or less at not less than 10Å, and does

not contain aluminum, A presentation differs from this 1st layer, and it has thickness of 100A or less at not less than 10A, The 3rd layer that consists of a nitride semiconductor which the 2nd layer that consists of a nitride semiconductor containing aluminum is the laminated superlattice layers, and said p side clad layer has thickness of 100A or less at not less than 10A, and does not contain aluminum, A nitride semiconductor device, wherein the 4th layer that consists of a nitride semiconductor which a presentation differs from this 3rd layer, and has thickness of 100A or less at not less than 10A, and contains aluminum is the laminated superlattice layers.

[Claim 19]The nitride semiconductor device according to claim 18 by which a Mine-like ridge part was formed in a resonant direction in a layer currently formed above said p side clad layer and this p side clad layer.

[Claim 20]A nitride semiconductor device given in any 1 clause of the Claims 1-19 which have a nitride semiconductor with which said active layer contains indium.

[Claim 21]Said nitride semiconductor device is a nitride semiconductor device given in any 1 clause among Claims 1-20 currently formed on C side of silicon on sapphire.

[Claim 22]It is a nitride semiconductor device given in any 1 clause among Claims 1-20 currently formed on a GaN board from which silicon on sapphire was removed after said nitride semiconductor device grows up a GaN layer which doped Si on C side of silicon on sapphire.

[Claim 23]Said n side light guide layer is a nitride semiconductor device given in any 1 clause among Claims 1-22 as for which GaN exists.

[Claim 24]Said n side light guide layer is a nitride semiconductor device given in any 1 clause among Claims 1-22 which are InGaN.

[Claim 25]Said p side light guide layer is a nitride semiconductor device given in any 1 clause among Claims 1-24 which are GaN.

[Claim 26]Said p side light guide layer is a nitride semiconductor device given in any 1 clause among Claims 1-24 which are InGaN.

[Claim 27]Said nitride semiconductor device touches said active layer, and it has the p side cap layer which consists of a nitride semiconductor containing aluminum, It is a nitride semiconductor device given in any 1 clause among Claims 1-26 which have the p side light guide layer in which bandgap energy is smaller than said p side cap layer in a position which is separated from an active

layer rather than the p side cap layer.

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## DETAILED DESCRIPTION

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[Detailed Description of the Invention]

[0001]

[Field of the Invention] This invention Light emitting devices, such as LED (light emitting diode) and LD (laser diode), It is related with the element which consists of a nitride semiconductor ( $\text{In}_x\text{Al}_y\text{Ga}_{1-x-y}\text{N}$ ,  $0 \leq x$ ,  $0 \leq y$ ,  $x+y \leq 1$ ) used for electron devices, such as photo detectors, such as a solar cell and a photosensor, or a transistor. a layer which general formula  $\text{In}_x\text{Ga}_{1-x}\text{N}$ ,  $\text{aluminum}_y\text{Ga}_{1-y}\text{N}$ , etc. which are used in this Description only show the empirical formula of a nitride semiconductor layer, and is different -- for example, even if shown by the same general formula, It is not shown till the X value of those layers and Y value being in agreement.

[0002]

[Description of the Prior Art] The nitride semiconductor was just put in practical use with a full color LED display, a traffic signal, etc. as a material of

high-intensity blue LED and authentic green LED recently. LED used for these various devices has a double structure into which the active layer which consists of InGaN of single quantum well structure (SQW:Single-Quantum- Well) between a n type nitride semiconductor layer and a p type nitride semiconductor layer was inserted. Wavelength, such as blue and green, is determined by fluctuating In composition ratio of an InGaN active layer.

[0003] These people announced the 410-nm laser oscillation in the room temperature for the first time under pulse current in the world recently using this material (for example, Jpn.J.Appl.Phys. Vol.35 (1996) pp.L74-76). This laser device is the conditions of 2 microseconds of pulse width, and 2 ms of pulse cycles, and shows the threshold current of 610 mA, threshold current density 8.7 kA/cm<sup>2</sup>, and a 410-nm oscillation. The threshold current announced the improved low laser device further again in Appl.Phys.Lett., Vol.69, No.10, 2 Sep. 1996, and p.1477-1479. This laser device has the structure where the ridge stripe was formed in a part of p type nitride semiconductor layer.

1 microsecond of pulse width, 1 ms of pulse cycles, and 0.1% of duty ratio show the threshold current of 187 mA, threshold current density 3 kA/cm<sup>2</sup>, and a 410-nm oscillation.

[0004]

[Problem to be solved by the invention]The blue and green LED which consist of nitride semiconductors are forward current ( $I_f$ )20mA, and compared with red LED which forward voltage ( $V_f$ ) becomes from the semiconductor of 3.4V - those with 3.6V, and a GaAlAs system, as for more than 2V, since it is high, a fall of further  $V_f$  is desired. In LD, the current in a threshold value and voltage are still high, and in order to carry out continuous oscillation at a room temperature, it is necessary to realize the element that this threshold current and voltage fall and that power efficiency is still higher.

[0005]Therefore, by reducing the current in the threshold value of the LD element which mainly consists of nitride semiconductors, and voltage, the place made into the purpose of this invention realizes continuous oscillation, and reduces  $V_f$  in a LED element, is reliable, and there is in realizing the nitride semiconductor device excellent in power efficiency.

[0006]

[Means for solving problem]As a result of examining a nitride semiconductor device wholeheartedly that the p type layer which sandwiched the active layer,

and/or a n type layer should be improved, this invention persons by using superlattice layers for the p type layer except an active layer, and/or a n type layer, The crystallinity of the layer using superlattice layers can be made good, and it newly finds out that said problem is solvable, and came to accomplish this invention.

[0007]Namely, the 1st nitride semiconductor device concerning this invention, The n type nitride semiconductor layer field where n side contact layer, the n side clad layer, and the n side light guide layer were laminated on the substrate, It is a nitride semiconductor device which has the p type nitride semiconductor layer field where the active layer which consists of nitride semiconductors, the p side light guide layer and a p side clad layer, and p side contact layer were laminated, The 1st layer that consists of a nitride semiconductor which said p side clad layer has thickness of 100A or less at not less than 10A, and does not contain aluminum, A presentation differs from this 1st layer, and it has thickness of 100A or less at not less than 10A, and the 2nd layer that consists of a nitride semiconductor containing aluminum is characterized by being the laminated superlattice layers. Since the resistance of the p type nitride semiconductor layer which consists of said superlattice layers can be made very low by this, power

efficiency of a nitride semiconductor device can be made high. In the 1st nitride semiconductor device concerning this invention, said superlattice layers, Since the 2nd layer that consists of a nitride semiconductor which the 1st layer, this 1st layer, and presentation which consist of a nitride semiconductor which has thickness of 100A or less differ from each other, and has thickness of 100A or less is laminated, the crystallinity of said superlattice layers can improve. the threshold current by applying a superstructure to a p type cladding layer, and voltage -- it seems to be low -- \*\*\*\*\* can be large and a threshold current and voltage can be notably reduced in this invention.

[0008]It is preferred to dope a p type impurity in the 1st nitride semiconductor device concerning this invention in either [ at least ] said 1st layer or said 2nd layer, and, as for the concentration of the p type impurity doped by said 1st layer and said 2nd layer, differing mutually is preferred. When the bandgap energy of said 1st layer and said 2nd layer differs mutually in the 1st nitride semiconductor device of the above, it is preferred that bandgap energy enlarges impurity concentration of a large layer.

[0009]The 2nd nitride semiconductor device concerning this invention, The n type nitride semiconductor layer field where n side contact layer, the n side clad



layer, and the n side light guide layer were laminated on the substrate, It is a nitride semiconductor device which has the p type nitride semiconductor layer field where the active layer which consists of nitride semiconductors, the p side light guide layer and a p side clad layer, and p side contact layer were laminated, Among said p side clad layer and said n side clad layer, at least one. It has thickness of 100A or less at not less than 10A, and a presentation differs from the 1st layer that consists of a nitride semiconductor which does not contain aluminum, and this 1st layer, and it has thickness of 100A or less at not less than 10A, and the 2nd layer that consists of a nitride semiconductor containing aluminum is characterized by being the laminated superlattice layers.

[0010]In the 2nd nitride semiconductor device concerning this invention, when said p side clad layers are said superlattice layers, It is preferred to dope a p type impurity in either [ at least ] said 1st layer or said 2nd layer, and, as for the concentration of the p type impurity doped by said 1st layer and said 2nd layer, differing mutually is preferred. When the bandgap energy of said 1st layer and said 2nd layer differs mutually in the 2nd nitride semiconductor device concerning this invention, it is preferred that bandgap energy enlarges impurity concentration of a large layer.

[0011]In the 2nd nitride semiconductor device concerning this invention, when said n side clad layers are said superlattice layers, It is preferred to dope a n type impurity in either [ at least ] said 1st layer or said 2nd layer, and it is preferred that the concentration of the n type impurity doped without the 1st layer of an account and said 2nd layer differs mutually. Under the present circumstances, when the bandgap energy of said 1st layer and said 2nd layer differs mutually, it is preferred that bandgap energy enlarges impurity concentration of a large layer.

[0012]The 3rd nitride semiconductor device concerning this invention, The n type nitride semiconductor layer field where n side contact layer, the n side clad layer, and the n side light guide layer were laminated on the substrate, It is a nitride semiconductor device which has the p type nitride semiconductor layer field where the active layer which consists of nitride semiconductors, the p side light guide layer and a p side clad layer, and p side contact layer were laminated, The 1st layer that consists of a nitride semiconductor with which said n side clad layer has thickness of 100Å or less at not less than 10Å, and does not contain aluminum, A presentation differs from this 1st layer, and it has thickness of 100Å or less at not less than 10Å, The 3rd layer that consists of a nitride

semiconductor which the 2nd layer that consists of a nitride semiconductor containing aluminum is the laminated superlattice layers, and said p side clad layer has thickness of 100A or less at not less than 10A, and does not contain aluminum, A presentation differs from this 3rd layer, and it has thickness of 100A or less at not less than 10A, and the 4th layer that consists of a nitride semiconductor containing aluminum is characterized by being the laminated superlattice layers.

[0013]It may be made to form a Mine-like ridge part in a resonant direction in the 3rd nitride semiconductor device of the above in the layer currently formed above said p side clad layer and this p side clad layer.

[0014]In the 1st concerning this invention - the 3rd nitride semiconductor device, said active layer may have a nitride semiconductor containing indium. Said 1st [ the ] - the 3rd nitride semiconductor device, It may be made to form on C side of silicon on sapphire, and after said 1st [ the ] - the 3rd nitride semiconductor device grow up the GaN layer which doped Si on C side of silicon on sapphire, it may be made to form them on the GaN board from which silicon on sapphire was removed. In said 1st [ the ] - the 3rd nitride semiconductor device, said n side light guide layer may be GaN, and may be InGaN. In said 1st [ the ] - the 3rd

nitride semiconductor device, said p side light guide layer may be GaN, and may be InGaN. Said active layer is touched in said 1st [ the ] - the 3rd nitride semiconductor device, It is preferred to provide the p side light guide layer in which bandgap energy is smaller than said p side cap layer in the position which has the p side cap layer which consists of a nitride semiconductor containing aluminum, and is separated from an active layer rather than the p side cap layer.

[0015]The 1st layer that consists superlattice layers of  $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0 \leq x \leq 1$ ) in the 1st - the 3rd nitride semiconductor device of this invention, If constituted by laminating the 2nd layer that consists of  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  ( $0 \leq y \leq 1$ ,  $x=y \neq 0$ ),

General formula  $\text{Al}_y\text{Ga}_{1-y}\text{N}$ - Since a good crystalline semiconductor layer is obtained, the nitride semiconductor expressed with  $\text{Al}_y\text{N}$  and  $\text{In}_x\text{Ga}_{1-x}\text{N}$  can form a layer with few crystal defects.

Thereby, the crystallinity of the whole nitride semiconductor becomes good, and when improvement (improvement in power efficiency) and this element are a LED element or an LD element about the output of this element,  $V_f$ , a threshold current, voltage, etc. can be made low. In the 1st of this invention - the 3rd nitride semiconductor device. In said superlattice layers in order to form a layer with still few crystal defects, It is still more preferred that said 1st layer consists of a nitride semiconductor expressed with formula  $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0 \leq x < 1$ ), and said 2nd

layer consists of a nitride semiconductor expressed with formula aluminum<sub>Y</sub>Ga<sub>1-Y</sub>N (0< Y<1).

[0016]In the 1st - the 3rd nitride semiconductor device of this invention, although it is preferred that it is 70Å or less as mentioned above as for the thickness of said 1st layer and the 2nd layer, it is set as 40Å or less still more preferably. In this invention, the thickness of said 1st layer and the 2nd layer is set as not less than 10Å. By setting up within the limits of this, nitride semiconductor layers, such as aluminum<sub>Y</sub>Ga<sub>1-Y</sub>N (0< Y<=1) which was hard to grow up, can form with sufficient crystallinity by the former. Of the p type nitride semiconductor layers which are between p electrode and an active layer especially, at least further, And/or, when making into superlattice layers at least one layer in the n type nitride semiconductor layer between n side contact layer as a current injection layer and the active layer in which n electrode is formed, the effect by setting the 1st layer that constitutes the superlattice layers, and the 2nd layer as said thickness is large.

[0017]In the 1st - the 3rd nitride semiconductor device of this invention, it is preferred to have p side contact layer for forming p electrode, and to set the thickness of these p side contact layers as 500Å or less. Thus, the resistance of

the thickness direction of these p side contact layers can be lowered by forming p side contact layer thinly. It is still more preferred to set it as 300A or less in this invention. As for the minimum of the thickness of these p side contact layers, it is preferred to set it as not less than 10A so that the semiconductor layer under this p type contact layer may not be exposed.

[0018]moreover -- forming the 1st buffer layer on a substrate and forming on it the 2nd buffer layer that consists of a nitride semiconductor of 0.1 micrometers or more of thickness in this invention, -- this -- it is preferred to form n side contact layer which consists of a nitride semiconductor with which the n type impurity was doped on the 2nd buffer layer. By this, carrier concentration can form good large crystalline n side contact layer. In order to form said 2nd buffer layer with still more sufficient crystallinity, it is preferred that the impurity concentration of said 2nd buffer layer is low concentration as compared with said n side contact layer.

[0019]In this invention, as an impurity which determines a conductivity type, the [ which is doped by the nitride semiconductor / periodic table ] -- the [ 4A fellows, 4B fellows, and ] -- the [ 6A fellows and ] -- there are a n type impurity belonging to 6B fellows and a p type impurity belonging to 1A, 1B fellows, 2A fellows, and

2B follows (this Description is hereafter described as a n type impurity and a p type impurity suitably.). As mentioned above, when bandgap energy differs in the 1st layer and 2nd layer, it is desirable to enlarge impurity concentration of a layer with larger bandgap energy. By this, a high increase in power by the abnormal-conditions dope at the time of forming superlattice layers in the p type nitride semiconductor layer side is expectable. In this invention, n side contact layers may be superlattice layers. Bandgap energy can differ mutually in two layers which constitute the superlattice layers which are n side contact layers, and power efficiency can be raised by enlarging impurity concentration of a layer with larger bandgap energy by an effect which was similar to HEMT mentioned later. For example, in a laser device, it is in threshold voltage and the tendency for a threshold current to fall, further.

[0020]

[Mode for carrying out the invention] Hereafter, the nitride semiconductor device of the embodiment which starts this invention with reference to Drawings is explained.

Embodiment 1. drawing 1 is the structure of the nitride semiconductor device of Embodiment 1 concerning this invention a shown typical sectional view, and this

nitride semiconductor device, As a fundamental structure, on the substrate 1 which consists of sapphire, The buffer layer 2 which consists of GaN(s), the n side contact layer 3 which consists of Si-dope n type GaN, the active layer 4 which consists of InGaN of single quantum well structure, the p side clad layer 5 which consists of superlattice layers by which the 1st layer that differs in a presentation mutually, and the 2nd layer were laminated, The p side contact layer 6 which consists of Mg dope GaN is the LED element laminated in order. In the nitride semiconductor device of Embodiment 1, all over almost [ of the p side contact layer 6 surface ], The whole surface electrode 7 of translucency is formed, the p electrode 8 for bonding is formed in the surface of the whole surface electrode 7, and the n electrode 9 is formed in the surface of the n side contact layer 2 further exposed from the p side contact layer 6 by carrying out etching removal of a part of nitride semiconductor layer.

[0021]The 1st layer of 30 Å of thickness (A) which consists of  $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0 \leq x \leq 1$ ) in which the nitride semiconductor device of Embodiment 1 doped Mg, for example as a p type impurity here, Since it has the p side clad layer 5 which has the low resistance which comprised superlattice layers by which the 2nd layer of 30 Å of thickness which consists of p type aluminum $\gamma$ Ga $_{1-\gamma}$ N



( $0 \leq Y \leq 1$ ) which similarly doped Mg in the 1st layer and takes doses as a p type impurity was laminated,  $V_f$  can be made low. Thus, when forming superlattice layers in the p layer side, it is considered as the superlattice layers which dope p type impurities, such as Mg, Zn, Cd, and Be, in the 1st layer and/or the 2nd layer, and have a p type conductivity type. as laminating order -- the -- the [ 1+ ] -- the [ 2+the 1st ... or, and ] -- the [ 2+ ] -- the order of 1+the 2nd ... may be sufficient, and at least a total of two or more layers are laminated.

[0022]The 1st layer and 2nd layer that consist of a nitride semiconductor which constitutes superlattice layers, It is not necessarily limited to the layer which consists of the layer and aluminum<sub>Y</sub>Ga<sub>1-Y</sub>N ( $0 \leq Y \leq 1$ ) which consist of In<sub>X</sub>Ga<sub>1-X</sub>N ( $0 \leq X \leq 1$ ), and what is necessary is just to comprise a nitride semiconductor with which presentations differ mutually. The bandgap energy of the 1st layer and the 2nd layer may differ, or it may be the same. For example, if the 1st layer is constituted from In<sub>X</sub>Ga<sub>1-X</sub>N ( $0 \leq X \leq 1$ ) and the 2nd layer is constituted from aluminum<sub>Y</sub>Ga<sub>1-Y</sub>N ( $0 < Y \leq 1$ ), the bandgap energy of the 2nd layer will certainly become larger than the 1st layer, but. If the 1st layer is constituted from In<sub>X</sub>Ga<sub>1-X</sub>N ( $0 \leq X \leq 1$ ) and the 2nd layer is constituted from In<sub>Z</sub>Al<sub>1-Z</sub>N ( $0 < Z \leq 1$ ), bandgap energy may be the same although the 1st layer

and 2nd layer differ in a presentation. If the 1st layer is constituted from aluminum<sub>Y</sub>Ga<sub>1-Y</sub>N ( $0 \leq Y \leq 1$ ) and the 2nd layer is constituted from In<sub>Z</sub>Al<sub>1-Z</sub>N ( $0 \leq Z \leq 1$ ), bandgap energy may be the same although the 1st layer and 2nd layer differ in a presentation similarly. That is, as long as this invention is superlattice layers which have the operation mentioned later, its bandgap energy of the 1st layer and the 2nd layer may be the same, or they may differ. As mentioned above, since [ which differs in a presentation ] a film is laminated extremely and the thickness of each layer is thin enough, the superlattice layers said here are large concepts which say the thing of the layer laminated without the defect accompanying a stacking fault occurring, and include quantum well structure. Although these superlattice layers do not have a defect inside, since they have the distortion accompanying a stacking fault, they are also usually called a strained super lattice. In this invention, even if V group elements, such as As and P, replace a part of N (nitrogen) of the 1st layer and the 2nd layer, as long as N exists, it is contained in a nitride semiconductor.

[0023] In this invention, the thickness of the 1st layer and the 2nd layer which constitutes superlattice layers, Since the 1st layer and 2nd layer will serve as thickness beyond an elastic strain limit and a very small crack or a crystal defect

will enter easily into this film if thicker than 100 Å, it is preferred to set it as thickness of 100 Å or less. The minimum in particular of the thickness of the 1st layer and the 2nd layer is not limited, but should just be one or more atomic layers. However, in this invention the thickness of the 1st layer and the 2nd layer, The critical (elastic strain) marginal thickness of a nitride semiconductor is not fully reached as it is 100 Å, It is most preferred for setting it as 70 Å or less to set up desirable still more desirable more thinly, in order to use below elastic strain marginal thickness and to lessen the crystal defect of a nitride semiconductor more, and to set it as 40 Å - 10 Å. Although it may be set as 10 Å or less (one atomic layer or two atomic layers) in this invention, if it is set as 10 Å or less, For example, as for the thickness of the 1st layer and the 2nd layer, since formation time and time and effort are taken on \*\* more than which the number of laminations increases, and a manufacturing process when forming the cladding layer of thickness of 500 Å or more by superlattice layers, it is preferred to set up more thickly than 10 Å.

[0024]In the case of the nitride semiconductor device of this Embodiment 1 shown in drawing 1, the p type clad layer 5 which consists of superlattice layers is formed between the active layer 4 and the p side contact layer 6 which is

current injection layers, and is acting as a carrier confining layer. Thus, to make especially superlattice layers into a carrier confining layer, it is necessary to make average bandgap energy of superlattice layers larger than an active layer. In a nitride semiconductor, since the nitride semiconductor containing aluminum, such as AlN, AlGa<sub>N</sub>, and InAlN, has comparatively big bandgap energy, these layers are used as a carrier confining layer. However, if a thick film is grown up by an AlGa<sub>N</sub> single like before, it has the character in which a crack enters easily into crystal growth.

[0025] Then, the nitride semiconductor which contains aluminum at least in this invention for either [ at least ] the 1st layer of superlattice layers, or the 2nd layer, By forming aluminum<sub>Y</sub>Ga<sub>1-Y</sub>N (0< Y<=1) by the thickness below an elastic strain limit preferably, and constituting superlattice layers, growth formation of the good crystalline superlattice layers is carried out very much, and bandgap energy forms the layer big moreover with few cracks. In this case, it is made hard to act also as a buffer layer at the time of growing up the 2nd layer that consists of a nitride semiconductor containing aluminum, if the nitride semiconductor layer which does not contain aluminum in the 1st layer is grown up by thickness of 100 Å or less still more preferably, and to go into the 2nd layer in a crack. Therefore,

even if it laminates the 1st layer and 2nd layer, good crystalline superlattice layers without a crack can be formed. Therefore, in this Embodiment 1, it is preferred to use superlattice layers as the 1st layer (the 2nd layer) that consists of  $\text{In}_X\text{Ga}_{1-X}\text{N}$  ( $0 \leq X \leq 1$ ), and the 2nd layer (the 1st layer) that consists of  $\text{Aluminum}_Y\text{Ga}_{1-Y}\text{N}$  ( $0 \leq Y \leq 1$ ,  $X \neq Y = 0$ ).

[0026] In the nitride semiconductor device of this Embodiment 1, in order to adjust carrier concentration to at least one layer of the 1st layer and the 2nd layer which constitute the p side clad layer 5 which is superlattice layers, it is preferred that the p type impurity which sets the conductivity type of this layer as a p type is doped. Dope \*\* is also good by the concentration in which the 1st layer differs from the 2nd layer when doping a p type impurity in the 1st layer and 2nd layer, and when the bandgap energy of the 1st layer and the 2nd layer differs, it is still more desirable for bandgap energy to make the big layer high concentration. It is because the carrier concentration of one layer can become high substantially and the resistance of the whole superlattice layers can be reduced according to the quantum effect by abnormal-conditions doping, if an impurity is doped by concentration which is different in the 1st layer and the 2nd layer, respectively. Thus, in this invention, an impurity may be doped by different

concentration in both the 1st layer and the 2nd layer, respectively, and an impurity may be doped in the 2nd either one of 1st layer or layer.

[0027]The impurity concentration doped by the 1st layer and 2nd layer, Although this invention in particular is not limited to this, usually with a p type impurity  $1 \times 10^{16}/\text{cm}^3$  -  $1 \times 10^{22}/\text{cm}^3$ , It is still more preferably desirable  $1 \times 10^{17}/\text{cm}^3$  -  $1 \times 10^{21}/\text{cm}^3$ , and to adjust to the range of  $1 \times 10^{18}/\text{cm}^3$  -  $2 \times 10^{20}/\text{cm}^3$  most preferably. It is because it is in the tendency for the crystallinity of superlattice layers to worsen when more [ if less than  $1 \times 10^{16}/\text{cm}^3$ , the effect of reducing  $V_f$  and threshold voltage will be hard to be acquired, and ] than  $1 \times 10^{22}/\text{cm}^3$ . It is desirable to also adjust a n type impurity to the same range. The Reason is the same.

[0028]However, in this invention, the impurity which determines a conductivity type as the 1st layer and 2nd layer does not need to be doped by superlattice layers. The superlattice layers by which this impurity is not doped may be which layers between an active layer and a substrate, as long as they are n type nitride semiconductor layer fields, and on the other hand, as long as they are p type nitride semiconductor layer fields, they may be which layers between a carrier confining layer (optical confinement layer) and an active layer.

[0029]Since the 1st layer and the 2nd layer are made into the thickness below an

elastic strain limit, are laminated and the superlattice layers constituted as mentioned above form them, the lattice defect of a crystal can be reduced, and they can decrease a very small crack, and can improve crystallinity fast. As a result, without spoiling crystallinity not much, increase doped quantity of an impurity for it and by this. Since it can move without being able to make the carrier concentration of a n type nitride semiconductor layer and a p type nitride semiconductor layer increase, and scattering about these carriers according to a crystal defect, as compared with the nitride semiconductor of a p type or a n type which does not have a superstructure, single or more figures resistivity can be made low.

[0030]Therefore, in the nitride semiconductor device (LED element) of this Embodiment 1. Obtaining a low resistance nitride semiconductor layer conventionally forms the p type clad layer 5 by the side of difficult p layer (p type semiconductor layer field (field which consists of the p type clad layer 5 and the p type contact layer 6)) using superlattice layers, By making low the resistance of this p type clad layer 5,  $V_f$  can be made low. That is, compared with a n type nitride semiconductor, resistivity is usually high [ a p type nitride semiconductor / a p type crystal is a semiconductor which is very hard to be obtained, and ], even

if a p type nitride semiconductor is obtained double or more figures. Therefore, by forming p type superlattice layers in the p layer side, the p type layer which comprised superlattice layers can be extremely made into low resistance, and the fall of  $V_f$  appears notably. in order to obtain a p type crystal conventionally, annealing of the nitride semiconductor layer which doped the p type impurity is carried out as technology, and the technology which produces a p type nitride semiconductor is known by removing hydrogen (patent No. 2540791). However, although the p type nitride semiconductor was obtained, the resistivity has more than number omega and cm. Then, crystallinity becomes good by making this p type layer into p type superlattice layers, according to our examination, this p layer resistivity [ single or more figures ] can be made low as compared with the former, and the effect that  $V_f$  makes it fall shows up notably.

[0031]In this Embodiment 1, the 1st layer (the 2nd layer) is preferably set to  $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0 \leq x \leq 1$ ) as mentioned above, Since the superlattice layers which do not have a good crystalline crack by constituting the 2nd layer (the 1st layer) from aluminum $_y\text{Ga}_{1-y}\text{N}$  ( $0 \leq y \leq 1$ ,  $x \neq y = 0$ ) can be formed, an element life can be raised.

[0032]Next, we compare and explain the conventional example and this



invention which were indicated by publicly known document containing the Patent Gazette for which it applied before. First, we proposed JP,H8-228048,A previously as technology similar to this invention. This technology is technology which forms the multilayer film which becomes the outside of the n type clad layer which sandwiches an active layer, and/or the outside (that is, side which is separated from an active layer) of a p type clad layer from AlGa<sub>N</sub>, GaN, InGa<sub>N</sub>, etc. as a light reflection film of a laser beam. Since a multilayer film is formed as a light reflection film, and the thickness of that each layer is designed by  $\lambda / 4n$  (n: the refractive index of a nitride semiconductor,  $\lambda$ :wavelength), this technology is dramatically thick. Therefore, each thickness of a multilayer film is not the thickness below an elastic strain limit. The laser device of the structure which inserted the active layer into USP No. 5,146,465 by the mirror which consists of aluminum<sub>x</sub>Ga<sub>1-x</sub>N/aluminum<sub>y</sub>Ga<sub>1-y</sub>N is indicated. In order to make AlGa<sub>N</sub>/AlGa<sub>N</sub> act as a mirror like [ this technology ] last technology, thickness of each layer must be thickened. It is dramatically difficult to laminate a many layers hard semiconductor still like AlGa<sub>N</sub> without a crack.

[0033]On the other hand, each thickness of the 2nd layer is set to the 1st constitute superlattice layers from this embodiment (both are preferably set to

100 Å or less and below critical thickness.), and it differs from said technology.

An effect by a strained super lattice of a nitride semiconductor which constitutes superlattice layers from this invention is used, crystallinity is raised, and  $V_f$  is reduced.

[0034] A method of laminating AlN and GaN of a thin film to JP,5-110138,A and JP,H5-110139,A, and obtaining a crystal of aluminum<sub>y</sub>Ga<sub>1-y</sub>N is indicated. In order to obtain a mix crystal of aluminum<sub>y</sub>Ga<sub>1-y</sub>N of a predetermined mixed crystal ratio, this technology is technology which laminates AlN of tens of Å thickness, and GaN, and differs from technology of this invention. And since it does not have an active layer which consists of InGaN(s), a crack goes into superlattice layers easily. A light emitting device of terrorism structure is indicated by JP,H6-21511,A and the No. 268257 [ six to ] gazette to double which has an active layer of multiple quantum well structure which laminated GaN, InGaN or InGaN, and InGaN. In this invention, it is the technology which makes layers other than an active layer multiple quantum well structure, and differs also from this technology.

[0035] Furthermore, with the element of this invention, when equipping an active layer with a nitride semiconductor like InGaN which contains indium at least, the

effect of superlattice shows up notably. Bandgap energy is small and the InGaN active layer is most suitable as an active layer of a nitride semiconductor device. Therefore, since an active layer, a bandgap energy difference, and refractive index difference can be enlarged if the superlattice layers which consist of  $\text{In}_x\text{Ga}_{1-x}\text{N}$  and aluminum  $\text{Ga}_{1-y}\text{N}$  are formed as a layer which sandwiches an active layer, When these superlattice layers realize a laser device, it operates as a dramatically outstanding optical confinement layer (it applies to the nitride semiconductor device of Embodiment 2). Since InGaN is [ the character of a crystal ] soft compared with the nitride semiconductor containing aluminum like other AlGaN(s), if InGaN is made an active layer, a crack will become furthermore difficult to go into each laminated whole nitride semiconductor layer. Conversely, when a nitride semiconductor like AlGaN is made into an active layer, since the character of the crystal is hard, it is in the tendency for a crack to go into the whole crystal easily.

[0036]It is desirable to adjust still more preferably 500 Å or less of thickness [ 300 Å or less of ] of p side contact layer to 200 Å or less most preferably furthermore. because, it mentioned above -- as -- resistivity -- several -- more than ohm-cm adjusts the thickness of a certain p type nitride semiconductor

layer to 500 Å or less -- further -- resistivity -- it seems to be low -- since \*\*\*\*\* is made, the current in a threshold value and voltage fall. Quantity of the hydrogen removed from a p type layer can be increased, and resistivity can be reduced further.

[0037]As mentioned above, in the nitride semiconductor device of this Embodiment 1, as explained in full detail, since the 1st layer and 2nd layer constitute the p type clad layer 5 from laminated superlattice layers, this p type clad layer 5 is extremely made to low resistance, and  $V_f$  of this element can be made low.

[0038]According to above Embodiment 1, although superlattice layers were used for the p side clad layer 5, this invention may use p type superlattice layers not only for this but for the p side contact layer 6. That is, the p side contact layer 6 into which current (electron hole) is poured can also be made into the p type superlattice layers by which the 1st layer that consists of  $\text{In}_x\text{Ga}_{1-x}\text{N}$ , and the 2nd layer that consists of  $\text{Aluminum}_y\text{Ga}_{1-y}\text{N}$  were laminated. When the p type contact layer 6 is made into superlattice layers and the bandgap energy of the 1st layer is smaller than the 2nd layer, It is preferred to consider it as the layer which bandgap energy makes the outermost surface the 1st layer that consists of small

$\text{In}_x\text{Ga}_{1-x}\text{N}$ , and contacts p electrode, contact resistance with p electrode becomes small, and desirable OMIKKU is obtained by this. This is because the direction of the 1st layer with small bandgap energy is in the tendency for the nitride semiconductor layer whose carrier concentration is higher than the 2nd layer to be easy to be obtained. When forming further an above-mentioned p side clad layer and p type nitride semiconductor layers other than p side contact layer in a p type nitride semiconductor layer field, superlattice layers may constitute this p type nitride semiconductor layer from this invention.

[0039]According to above Embodiment 1, although superlattice layers were used for the p side clad layer 5, this invention may use n type superlattice layers for the n side contact layer 3 of not only a p type nitride semiconductor layer field but a n type nitride semiconductor field. Thus, when making the n side contact layer 3 into superlattice layers, n type impurities, such as Si and germanium, can be doped in the 1st layer and/or 2nd layer, and superlattice layers which have a n type conductivity type can be formed as the n type contact layer 3 between the substrate 1 and the active layer 4, for example. In this case, it was checked that it is in a tendency for lateral resistance to fall if especially the n type contact layer 3 is made into superlattice layers which differ in impurity concentration, and for

threshold voltage and current to fall in LD.

[0040] This is about a case where superlattice layers which doped many n type impurities are formed in a direction of a big layer of bandgap energy as a contact layer by the side of a n layer. An effect in which an operation similar to the following HEMT(s) (High-Electron-Mobility-Transistor) appeared is guessed. The 1st layer with a large band gap by which a n type impurity was doped (the 2nd layer), A band gap in superlattice layers which laminated the 2nd layer (the 1st layer) of small undoping {(undope) the state where an impurity is not doped below as for; is called undoping}. By a heterojunction interface of a layer which added a n type impurity, and a undoped layer, the big layer side of bandgap energy depletion-izes, and an electron (two dimensional electron gas) is accumulated in an interface before and behind thickness (100 Å) by the side of a small layer of bandgap energy. In order not to receive dispersion by an impurity when an electron runs since this two dimensional electron gas turns on a small layer side of bandgap energy, the degree of electron transfer of superlattice layers becomes high, and is guessed that resistivity falls.

[0041] In this invention, when providing the cladding layer by the side of n in a n type nitride semiconductor layer field, it is good also considering the cladding

layer by the side of this n as superlattice layers. When forming n type nitride semiconductor layers other than n side contact layer and a n side clad layer in a n type nitride semiconductor layer field, it is good also considering this n type nitride semiconductor layer as superlattice layers. However, when providing the nitride semiconductor layer which consists of superlattice layers in a n type nitride semiconductor layer field, it cannot be overemphasized that it is desirable to make into a superstructure the n side clad layer as a carrier confining layer or the n side contact layer 3 into which current (electron) is poured.

[0042]thus, when looking superlattice layers like [ the n type nitride semiconductor layer field between the active layer 4 and the substrate 1 ] and providing them, it is not necessary to dope an impurity in the 1st layer and the 2nd layer which constitute superlattice layers. It is because there is character which becomes a n type even when a nitride semiconductor is undoped. However, it is more desirable to dope n type impurities, such as Si and germanium, in the 1st layer and the 2nd layer, and to establish the difference of impurity concentration as mentioned above, when forming in the n layer side.

[0043]As mentioned above, crystalline improvement is mentioned like the case where the effect at the time of forming superlattice layers in a n type nitride

semiconductor layer field provides superlattice layers in a p type nitride semiconductor layer field. When it explains in detail, in the case of the nitride semiconductor device which has a hetero-junction, the carrier confining layer of a n type and a p type usually comprises AlGa<sub>N</sub> with larger bandgap energy than an active layer. Crystal growth is dramatically difficult for AlGa<sub>N</sub>, for example, when you are going to make it grow up by thickness of 0.5 micrometers or more with single composition, there is character in which a crack enters easily during a crystal. However, since a good crystalline thing will be obtained only in the 1st single layer and the 2nd layer if the 1st layer and the 2nd layer are laminated by the thickness below an elastic strain limit like this invention and it is superlattice layers, while crystallinity has been good also as thick superlattice layers of thickness, a cladding layer can grow the whole. Therefore, since the crystallinity of the whole nitride semiconductor becomes good and the mobility of a n type region becomes large,  $V_f$  falls with the element which made the superlattice layers the cladding layer. It seems that an effect similar to the above mentioned HEMT comes to show up notably when the impurity of Si and germanium is doped to superlattice layers and superlattice layers are made into a contact layer, and threshold voltage and  $V_f$  can be reduced further.



[0044]Thus, the cladding layer as a carrier confining layer formed in the n type region or p type region where superlattice layers sandwich an active layer in this invention, Since it is used as the light guide layer of an active layer, or a current injection layer formed by an electrode touching, it is desirable to adjust so that the average bandgap energy of the nitride semiconductor which constitutes superlattice layers may become larger than an active layer.

[0045]Embodiment 2 concerning embodiment 2., next this invention is described.

Drawing 2 is the structure of the nitride semiconductor device of Embodiment 2 concerning this invention a shown typical sectional view (section vertical to the resonant direction of a laser beam), and this nitride semiconductor device, For example, on the substrates 10, such as sapphire which makes C side a principal surface, A n type nitride semiconductor layer field. (it consists of the n side contact layer 12, the crack prevention layer 13, the n side clad layer 14, and the n side light guide layer 15.) -- by a p type nitride semiconductor field (it consists of the cap layer 17, the p side light guide layer 18, the p side clad layer 19, and the p side contact layer 20.). It is the nitride semiconductor laser diode element provided with the active layer 16 which consists of a sandwiched nitride semiconductor.

[0046]Here the nitride semiconductor device of this Embodiment 2, The threshold voltage of the nitride semiconductor device which is an LD element is low set up by forming the n side clad layer 14 in a n type nitride semiconductor layer field by superlattice layers, and forming the p side clad layer 19 in a p type nitride semiconductor field by superlattice layers. The nitride semiconductor device of Embodiment 2 which starts this invention with reference to this drawing 2 below is explained in detail.

[0047]In the nitride semiconductor device of this Embodiment 2, First, the n side contact layer 12 is formed via the buffer layer 11 and the 2nd buffer layer 112 on the substrate 10, further, on the n side contact layer 12, the crack prevention layer 13, the n side clad layer 14, and the n side light guide layer 15 are laminated, and a n type nitride semiconductor layer field is formed. The n lateral electrode 23 which carries out ohmic contact to the n side contact layer 12 is formed in the surface of the n side contact layer 12 exposed to the both sides of the crack prevention layer 13, respectively, and the n side pad electrode for wire bonding is formed on these n lateral electrodes 23, for example. And the active layer 16 which consists of nitride semiconductors is formed on the n side light guide layer 15, further, on this active layer 16, the cap layer 17, the p side light

guide layer 18, the p side clad layer 19, and the p side contact layer 20 are laminated, and a p type nitride semiconductor layer field is formed. The p lateral electrode 21 which carries out ohmic contact to these p side contact layers 20 is formed on the p side contact layer 20, and p side pad electrode for wire bonding is formed on these p lateral electrodes 21, for example. By the upper part of the p side contact layer 20 and the p side clad layer 19. By the ridge part of the shape of Mine extended for a long time being constituted by the resonant direction, and forming this ridge part in it, In the active layer 16, light is shut up crosswise (direction which intersects perpendicularly with a resonant direction), and laser oscillation of the resonator which resonates to the longitudinal direction of a ridge part is produced and carried out using the cleavage plane by which cleavage was carried out in the direction vertical to a ridge part (electrode of stripe shape).

[0048]Next, each component of the nitride semiconductor device of Embodiment 2 is explained.

(Substrate 10) R side besides the sapphire which makes C side the substrate 10 with a principal surface, Semiconductor substrates, such as SiC (6H, 4H, and 3C are included), ZnS, ZnO, GaAs, GaN, etc. besides the sapphire which makes A

side a principal surface, and other insulating substrates like a spinel ( $\text{MgAl}_2\text{O}_4$ ), can be used.

[0049](Buffer layer 11) The buffer layer 11 grows up AlN, GaN, AlGaIn, InGaIn, etc. at the temperature of 900 °C or less, for example, and is formed in a thickness number (10 Å - hundreds of Å). In order that this buffer layer 11 may ease the grating constant injustice of a substrate and a nitride semiconductor, it forms, but it is also possible to omit according to the growing method of a nitride semiconductor, the kind of substrate, etc.

[0050](The 2nd buffer layer 112) On said buffer layer 11, the 2nd buffer layer 112 is a layer which consists of a nitride semiconductor of the single crystal grown up at the elevated temperature rather than said buffer layer, and has a thick film rather than the buffer layer 11. the nitride semiconductor layer which this 2nd buffer layer 112 considers it as a layer with less n type impurity concentration than the n side contact layer 12 grown up into the next, or does not dope a n type impurity -- if it is a GaN layer preferably, the crystallinity of the 2nd buffer layer 112 will become good. If a n type impurity is most preferably set to undoped GaN, a nitride semiconductor with the most sufficient crystallinity will be obtained. If not less than several micrometers thickness tends to constitute n

side contact layer which forms the negative electrode like before from the single nitride semiconductor layer of high carrier concentration, it is necessary to grow up a layer with large n type impurity concentration. As for the layer of a thick film with large impurity concentration, crystallinity tends to worsen. For this reason, on a bad crystalline layer, even if it grows up other nitride semiconductors, such as an active layer, other layers will succeed a crystal defect and crystalline improvement cannot be expected. Then, before growing up 12 layers of n side contact layers, carrier concentration can grow up the good large crystalline n side contact layer 12 by growing up the 2nd good crystalline buffer layer 112 with small impurity concentration. As for the thickness of this 2nd buffer layer 112, it is still more preferably desirable most preferably to adjust to 1 micrometers or more and 20 micrometers or less 0.5 micrometers or more 0.1 micrometers or more. When the 2nd buffer layer 112 is thinner than 0.1 micrometer, the n type contact layer 12 with large impurity concentration must be grown up thickly, and it is in the tendency which can seldom expect crystalline improvement in the n side contact layer 12. When thicker than 20 micrometers, it is in the tendency for a crystal defect to increase easily in the 2nd buffer layer 112 the very thing. It is considered as the advantage into which the 2nd buffer layer 112 is grown up

thickly, and improvement in heat dissipation nature is mentioned. That is, when a laser device is produced, the life of a laser device improves that heat spreads easily in the 2nd buffer layer 112. Furthermore, the light leaking of a laser beam spreads within the 2nd buffer layer 112, and it becomes easy to obtain the laser beam near an ellipse form. The 2nd buffer layer 112 may be omitted when conductive substrates, such as GaN, SiC, and ZnO, are used for a substrate.

[0051](n side contact layer 12) The n side contact layer 12 is a layer which acts as a contact layer which forms the negative electrode, and it is desirable to adjust to 0.2 micrometers or more and 4 micrometers or less. If thinner than 0.2, when forming the negative electrode later, it is difficult to control an etching rate so that this layer may be exposed, and when not less than 4 micrometers is used, on the other hand, it is in the tendency for crystallinity to worsen under the influence of an impurity. The range of the n type impurity doped to the nitride semiconductor of this n side contact layer 12 The range of  $1 \times 10^{17}/\text{cm}^3$  -  $1 \times 10^{21}/\text{cm}^3$ , It is desirable to adjust to  $1 \times 10^{18}/\text{cm}^3$  -  $1 \times 10^{19}/\text{cm}^3$  still more preferably. Since the material of n electrode and desirable OMIKKU will become is hard to be obtained if smaller than  $1 \times 10^{17}/\text{cm}^3$ , In a laser device, a fall of a threshold current and voltage cannot be expected, but since the leakage current of the

element itself will increase and crystallinity will also worsen if larger than  $1 \times 10^{21}/\text{cm}^3$ , it is in the tendency for the life of an element to become short. In the n side contact layer 12, in order to make small ohmic contact resistance with the n electrode 23, it is desirable to make larger than the n cladding layer 14 concentration of the impurity which raises the carrier concentration of these n side contact layers 12. The n side contact layer 12 acts not as a contact layer but as a buffer layer, when providing the negative electrode in a substrate at the substrate rear side using conductive substrates, such as GaN, SiC, and ZnO.

[0052] At least one layer of the 2nd buffer layer 11 and the n side contact layers 12 can also be made into superlattice layers. If it is superlattice layers, the crystallinity of this layer will become good by leaps and bounds, and a threshold current will fall. Let the desirable n side contact layer 12 in which thickness is thinner than the 2nd buffer layer 11 be superlattice layers. In the case where the n side contact layer 12 is made into the superstructure which comes to laminate the 1st layer that differs in bandgap energy mutually, and the 2nd layer, By exposing the desirable small layer of bandgap energy and forming the n electrode 23, contact resistance with the n electrode 23 can be made low, and can reduce a threshold value. As a n type nitride semiconductor and a material

of the n electrode 23 in which desirable OMIKKU is obtained, metal or alloys, such as aluminum, Ti, W, Si, Zn, Sn, and In, are mentioned.

[0053]By making the n type contact layer 12 into the superlattice layers which differ in impurity concentration, lateral resistance can be made low by an effect similar to HEMT explained in Embodiment 1, and the threshold voltage of an LD element and current can be made low.

[0054](Crack prevention layer 13) The crack prevention layer 13 consists of  $\text{In}_{0.1}\text{Ga}_{0.9}\text{N}$  which  $\text{cm}^{-3}$  [ $5 \times 10^{18}$ ]-doped Si, for example, and has 500-A thickness, for example. This crack prevention layer 13 can prevent a crack from entering into the nitride semiconductor layer containing aluminum formed on it the n type nitride semiconductor containing In and by growing up InGaN preferably and forming. As for this crack prevention layer 13, it is preferred to make it grow up by 100 Å or more and 0.5 micrometer or less of thickness. If thinner than 100 Å, it will be hard to act as crack prevention as mentioned above, and when thicker than 0.5 micrometer, it is in the tendency for the crystal itself to be discolored in black. This crack prevention layer 13 may be omitted, when using the n side contact layer 12 as superlattice like this Embodiment 1, or when making into superlattice layers the n side clad layer 14 grown up into the next.



[0055](N side clad layer 14 which consists of n type superlattice) A n side clad layer, For example, it consists of n type  $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$  which  $\text{cm}^{-3}$   $[5 \times 10^{18}]$ -doped Si, The 1st layer that has 20-A thickness, and the 2nd layer that consists of undoped GaN and has 20-A thickness consist of superlattice layers laminated by turns, and it has 0.5 micrometer of thickness on the whole. This n type clad layer 14 acts as a carrier confining layer and an optical confinement layer, The nitride semiconductor which contains aluminum for one of layers when it is considered as superlattice layers, It is desirable to grow up AlGa $\text{N}$  preferably and 2 micrometers or less of 100 A or more can grow a good carrier confining layer by making it grow up at 500 A or more and 1 micrometer or less still more preferably. Although this n type clad layer 14 can also be grown up with a single nitride semiconductor, the good crystalline carrier confining layer where a crack does not have considering it as superlattice layers can be formed.

[0056](n side light guide layer 15) The n side light guide layer 15 consists of n type GaN which  $\text{cm}^{-3}$   $[5 \times 10^{18}]$ -doped Si, for example, and has 0.1 micrometer of thickness. As for this n side light guide layer 6, it is desirable to act as a light guide layer of an active layer, to grow up GaN and InGa $\text{N}$ , and to form, and it is usually desirable to make it grow up by 200 A - 1 micrometer of thickness still

more preferably 100 Å - 5 micrometers. This light guide layer 15 can also be made into superlattice layers. When making the n side light guide layer 15 and the n side clad layer 14 into superlattice layers, average bandgap energy of the nitride semiconductor layer which constitutes superlattice layers is made larger than an active layer. When considering it as superlattice layers, a n type impurity may be doped in either [ at least ] the 1st layer or the 2nd layer, and undoping may be sufficient. The superlattice by which a undoped nitride semiconductor independent or a undoped nitride semiconductor was laminated may be sufficient as this light guide layer 15.

[0057](Active layer 16) The well layer which the active layer 16 consists of  $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$  which doped Si by  $8 \times 10^{18}/\text{cm}^3$ , for example, and has 25-Å thickness, It consists of  $\text{In}_{0.051}\text{Ga}_{0.95}\text{N}$  which  $\text{cm}^{-3}$  [  $8 \times 10^{18}$  ]-doped Si, and constitutes from multiple quantum well structure (MQW) which has predetermined thickness by laminating by turns the barrier layer which has 50-Å thickness. In the active layer 16, an impurity may be doped to both a well layer and a barrier layer, and it may dope to either. When a n type impurity is doped, it is in the tendency for a threshold value to fall. Superlattice layers are distinguished in order to certainly laminate the small well layer of bandgap energy, and the barrier layer in which

bandgap energy is smaller than a well layer, in making the active layer 16 into multiple quantum well structure in this way. 100 Å or less of thickness [ 70 Å or less of ] of a well layer shall be 50 Å or less most preferably. 150 Å or less of thickness [ 100 Å or less of ] of a barrier layer shall be 70 Å or less most preferably.

[0058](p side cap layer 17) Rather than the active layer 16, bandgap energy is large, for example, consists of p type aluminum<sub>0.3</sub>Ga<sub>0.7</sub>N which cm<sup>-3</sup>[ 1x10<sup>20</sup>]-doped Mg, and the p side cap layer 17 has 200-Å thickness, for example. Although it is preferred in this Embodiment 2 to use the cap layer 17 in this way, since this cap layer is formed in thin thickness, it is good also as an i type which doped the n type impurity and with which the carrier was compensated by this invention. 0.1 micrometer or less of thickness [ 500 Å or less of ] of the p side cap layer 17 is most preferably adjusted to 300 Å or less still more preferably. It is because a crack enters easily into the p side cap layer 17 and a good crystalline nitride semiconductor layer cannot grow easily, if it is made to grow up by thickness thicker than 0.1 micrometer. It is because it becomes impossible to pass the p type capping layer 17 from which a carrier becomes that the thickness of the p side cap layer 17 is 0.1 micrometers or more with this energy

barrier according to the tunnel effect, When passage of the carrier by this tunnel effect is taken into consideration, it is preferred to set it as 500 Å or less and 300 Å or more to have mentioned above.

[0059]To the p side cap layer 17, in order to make an LD element easy to oscillate, it is preferred that the composition ratio of aluminum uses and forms large AlGa<sub>N</sub>, and it becomes easy to oscillate an LD element, so that this AlGa<sub>N</sub> is formed thinly. For example, if Y value is 0.2 or more aluminum<sub>Y</sub>Ga<sub>1-Y</sub>N, adjusting to 500 Å or less is desirable. Although the minimum in particular of the thickness of the p side cap layer 17 does not limit, it is desirable to form by thickness of 10 Å or more.

[0060](p side light guide layer 18) Bandgap energy is smaller than the p side cap layer 17, for example, consists of p type GaN which cm<sup>-3</sup>[ 1x10<sup>20</sup>]-doped Mg, and the p side light guide layer 18 has 0.1 micrometer of thickness. As for this p side light guide layer 18, it is desirable to act as a light guide layer of the active layer 16, to make it grow up by GaN and InGa<sub>N</sub> as well as the n side light guide layer 15, and to form. This layer acts as a desirable light guide layer by acting also as a buffer layer at the time of growing up the p side clad layer 19, and growing up 100 Å - 5 micrometers by 200 Å - 1 micrometer of thickness still more

preferably. Although this p side light guide layer usually dopes p type impurities, such as Mg, and considers it as a p type conductivity type, it is not necessary to dope an impurity in particular. This p side light guide layer can also be made into superlattice layers. When considering it as superlattice layers, a p type impurity may be doped in either [ at least ] the 1st layer or the 2nd layer, and undoping may be sufficient.

[0061](P side clad layer 19= superlattice layers) The p side clad layer 19, For example, the 1st layer that consists of p type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N which cm<sup>-3</sup>[ 1x10<sup>20</sup>]-doped Mg, and has 20-A thickness, for example, For example, it consists of p type GaN which cm<sup>-3</sup>[ 1x10<sup>20</sup>]-doped Mg, and the 2nd layer that has 20-A thickness consists of superlattice layers laminated by turns. This p side clad layer 19 acts as a carrier confining layer as well as the n side clad layer 14, and acts as a layer for reducing especially the resistivity of a p type layer. Although the thickness in particular of this p side clad layer 19 is not limited, either, it is desirable to form at 500 Å or more and 1 micrometer or less still more preferably 2 micrometers or less 100 Å or more.

[0062](p side contact layer 20) On the p side clad layer 19, the p side contact layer 20 consists of p type GaN which cm<sup>-3</sup>[ 2x10<sup>20</sup>]-doped Mg, for example,

and has 150-Å thickness, for example. This p side contact layer 20 can be constituted from p type  $\text{In}_x\text{Al}_y\text{Ga}_{1-x-y}\text{N}$  ( $0 \leq x$ ,  $0 \leq y$ ,  $x+y \leq 1$ ), and if referred to as GaN which doped Mg as mentioned above preferably, the p electrode 21 and the most desirable ohmic contact will be obtained. It is desirable to adjust still more preferably 500 Å or less of thickness [ 300 Å or less of ] of p side contact layer to 200 Å or less most preferably furthermore. because, it mentioned above -- as -- resistivity -- several -- more than ohm-cm adjusts the thickness of a certain p type nitride semiconductor layer to 500 Å or less -- further -- resistivity -- it seems to be low -- since \*\*\*\*\* is made, the current in a threshold value and voltage fall. Quantity of the hydrogen removed from a p type layer can be increased, and resistivity can be reduced further.

[0063]The p side contact layer 20 can also be made into superlattice layers in this invention. Especially in considering it as superlattice layers, it laminates the 1st layer and 2nd layer that differ in bandgap energy, the -- the [ 1+ ] -- the [ 2+ ] -- 1+ the 2+ ... as -- if it laminates and is finally made exposed [ a layer with smaller bandgap energy ], the p electrode 21 and desirable ohmic contact will be obtained. As a material of the p electrode 21, nickel, Pd, nickel/Au, etc. can be mentioned, for example.

[0064]The insulator layer 25 which consists of  $\text{SiO}_2$  is formed in the surface of a nitride semiconductor layer exposed between the p electrode 21 and the n electrode 23 in this Embodiment 2 as shown in drawing 2, The p pad electrode 22 electrically connected with the p electrode 21 via an opening formed in this insulator layer 25 and the n pad electrode 24 connected with the n electrode 23 are formed. this p pad electrode 22 extends surface area of the substantial p electrode 21 -- the p electrode side -- wire bonding -- being able to be made to carry out die bonding, on the other hand, the n pad electrode 24 prevents peeling of the n electrode 23.

[0065]The nitride semiconductor device of above Embodiment 2 is provided with the good crystalline p type clad layer 19 which is the superlattice layers which made the 1st layer and the 2nd layer the thickness below an elastic strain limit, and were laminated. By this, since the nitride semiconductor device of this Embodiment 2 can make low the single or more figures resistance of the p side clad layer 19 as compared with the p side clad layer which does not have a superstructure, it can make threshold voltage and current low.

[0066]The p side clad layer 19 which contains p type aluminum $\gamma$ Ga $_{1-\gamma}$ N in the nitride semiconductor device of this Embodiment 2 is touched, By forming the

thickness thinly with 500 Å or less by making the small nitride semiconductor of bandgap energy into the p side contact layer 20, The carrier concentration of the p side contact layer 20 becomes high substantially, p electrode and desirable OMIKKU are obtained, and the threshold current of an element and voltage can be made low. Since it has the 2nd buffer layer 112 before growing up n side contact layer, the crystallinity of the nitride semiconductor layer grown up on the 2nd buffer layer 112 becomes good, and a long lasting element can be realized. If n side contact layer grown up on the 2nd buffer layer 112 is preferably used as superlattice, lateral resistance becomes low and the low element of threshold voltage and a threshold current can be realized.

[0067]In equipping the active layer 16 with a nitride semiconductor like InGaN which contains indium at least in the LD element of this Embodiment 2, It is preferred that  $\text{In}_x\text{Ga}_{1-x}\text{N}$  and aluminum $\gamma\text{Ga}_{1-\gamma}\text{N}$  use the superlattice layers laminated by turns as a layer (the n side clad layer 14 and the p side clad layer 19) which sandwiches the active layer 16. By this, since the bandgap energy difference of the active layer 16 and these superlattice layers and refractive index difference can be enlarged, these superlattice layers can be operated as a dramatically outstanding optical confinement layer, when realizing a laser device.



Since InGaN is [ the character of a crystal ] soft compared with the nitride semiconductor containing aluminum like other AlGaN(s), if InGaN is made an active layer, a crack will become furthermore difficult to go into each laminated whole nitride semiconductor layer. The life of an LD element can be lengthened by this.

[0068]In the case of the semiconductor device of the double hetero structure of having the active layer 16 which has quantum well structure like this Embodiment 2, the active layer 16 is touched, The p side cap layer 17 which consists of a nitride semiconductor of 0.1 micrometer or less of thickness with larger bandgap energy than the active layer 16, and the p side cap layer 17 which consists of a nitride semiconductor which contains aluminum preferably are formed, The p side light guide layer 18 in which bandgap energy is smaller than the p side cap layer 17 is formed in the position which is separated from an active layer rather than the p side cap layer 17, It is dramatically more preferred than the p side light guide layer 18 to form the p side clad layer 19 which has a superstructure which contains a nitride semiconductor with a larger band gap than the p side light guide layer 18 and the nitride semiconductor which contains aluminum preferably in the position which is separated from an active layer. And

in order that the electron poured in from the n layer since bandgap energy of the p side cap layer 17 was enlarged may be prevented by this p side cap layer 17, and may be shut up and an electron may not overflow an active layer, the leakage current of an element decreases.

[0069]Although the nitride semiconductor device of above Embodiment 2 showed a structure desirable as a structure of a laser device, What is necessary is just to have at least one layer of n type superlattice layers from the active layer 16 in this invention to the lower n type nitride semiconductor layer field (n type layer side), What is necessary is just to also have at least one layer of p type superlattice layers from the active layer 16 to the upper p type nitride semiconductor layer field (p type layer side), and element composition in particular is not specified. However, said superlattice layers are formed in the p side clad layer 19 as a carrier confining layer when forming in the p layer side, When forming in the n layer side and forming as the n contact layer 12 as a current injection layer which the n electrode 23 touched, or the n cladding layer 14 as carrier \*\*\*\*\* reduces  $V_f$  of an element, and a threshold value, it is in the most desirable tendency. It cannot be overemphasized that the same composition as the element of Embodiment 2 is applicable to a LED element

(however, in a LED element, a ridge part is unnecessary).

[0070]In the nitride semiconductor device of Embodiment 2 constituted as mentioned above. In the atmosphere which does not contain H, for example, a nitrogen atmosphere, after each layer is formed, It is preferred to perform annealing, for example at 700 °C not less than 400 °C, and since each layer of a p type nitride semiconductor layer field can be further low-resistance-ized by this, threshold voltage can be further made low by this.

[0071]In a nitride semiconductor device of Embodiment 2, the p electrode 21 which becomes the surface of the p side contact layer 12 from nickel and Au was formed in stripe shape, n side contact layer was symmetrically exposed to this p electrode 21, and the n electrode 23 is formed all over almost [ of that n side contact layer surface ]. Thus, when structure of forming the n electrode 23 symmetrically with both sides of the p electrode 21 when an insulating substrate is used makes threshold voltage low, it is dramatically advantageous.

[0072]In this Embodiment 2, a dielectric multilayer which consists of SiO<sub>2</sub> and TiO<sub>2</sub> may be formed in a cleavage plane (resonator face) which carried out cleavage in a direction vertical to a ridge part (electrode of stripe shape).

[0073]Thus, a cladding layer as a carrier confining layer formed in a n type

region or a p type region where superlattice layers sandwich an active layer in this invention, Since it is used as a light guide layer of an active layer, or a current injection layer formed by an electrode touching, it is desirable to adjust so that average bandgap energy of a nitride semiconductor which constitutes superlattice layers may become larger than an active layer.

[0074]

[Working example] Hereafter, in working example, this invention is explained in full detail.

[Working example 1] Working example 1 concerning this invention is an example of creation of a nitride semiconductor device (LD element) shown in drawing 2, and is produced in the following procedures. First, passing hydrogen, after setting the substrate 10 which consists of sapphire (C side) in a reaction vessel and replacing inside of a container enough from hydrogen, temperature of a substrate is raised to 1050 °C and a substrate is cleaned. Then, temperature is lowered to 510 °C, hydrogen is used for carrier gas, ammonia (NH<sub>3</sub>) and TMG (trimethylgallium) are used for material gas, and the 1st buffer layer 11 that comes from GaN on the substrate 10 is grown up by about 200-Å thickness.

[0075] Only TMG is stopped after buffer layer 11 growth, and temperature is

raised to 1050 °C. If it becomes 1050 °C, similarly TMG and ammonia gas will be used for material gas, and the 2nd buffer layer 112 that consists of the undoped GaN of carrier concentration  $1 \times 10^{18} / \text{cm}^3$  will be grown up by 5-micrometer thickness. the 2nd buffer layer --  $\text{In}_x\text{Al}_y\text{Ga}_{1-x-y}\text{N}$  ( $0 \leq x$ .) Although it can constitute from  $0 \leq y$  and  $x+y \leq 1$  and the presentation in particular is not asked, it is preferably undoped and aluminum (Y value) sets to 0.1 or less aluminum $_y\text{Ga}_{1-y}\text{N}$  and most desirable undoped GaN. Then, silane gas ( $\text{SiH}_4$ ) is used for TMG, ammonia, and impurity gas at 1050 °C, and the n side contact layer 12 which consists of n type GaN which  $\text{cm}^{-3}$  [ $1 \times 10^{19}$ ]-doped Si is grown up by 1 micrometer of thickness. When this n side contact layer 12 is formed by superlattice, it is still more preferred.

[0076] Temperature shall be 800 °C and to material gas Next, TMG, TMI (trimethylindium), Silane gas is used for ammonia and impurity gas, and the crack prevention layer 13 which consists of  $\text{In}_{0.1}\text{Ga}_{0.9}\text{N}$  which  $\text{cm}^{-3}$  [ $5 \times 10^{18}$ ]-doped Si is grown up by 500-Å thickness. And temperature shall be 1050 °C and TMA, TMG, ammonia, and silane gas are used, The 1st layer that consists of n type aluminum $_{0.2}\text{Ga}_{0.8}\text{N}$  which  $\text{cm}^{-3}$  [ $5 \times 10^{18}$ ]-doped Si is grown up by 20-Å thickness, then TMA and Silane are stopped and the 2nd layer that consists of

the undoping GaN is grown up by 20-A thickness. And this operation is repeated 100 times, respectively and the n side clad layer 14 which consists of superlattice layers of 0.4 micrometer of the total thickness is grown up.

[0077]Then, the n side light guide layer 15 which consists of n type GaN which  $\text{cm}^{-3}$  [  $5 \times 10^{18}$  ]-doped Si at 1050 \*\* is grown up by 0.1 micrometer of thickness.

Next, the active layer 16 is grown up using TMG, TMI, ammonia, and Silang. The active layer 16 holds temperature at 800 \*\*, and grows up the well layer which consists of  $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$  which doped Si by  $8 \times 10^{18}/\text{cm}^3$  first by 25-A thickness.

Next, the barrier layer which consists of  $\text{In}_{0.01}\text{Ga}_{0.99}\text{N}$  which  $\text{cm}^{-3}$  [  $8 \times 10^{18}$  ]-doped Si at the same temperature only by changing the mole ratio of TMI is grown up by 50-A thickness. This operation is repeated twice and the active layer 16 of the multiple quantum well structure (MQW) of 175 A of the total thickness that finally laminated the well layer is grown up.

[0078]Raise temperature to 1050 \*\* and to material gas Next, TMG, TMA, ammonia,  $\text{Cp}_2\text{Mg}$  (magnesium cyclopentadienyl) is used for impurity gas, The p side cap layer 17 which consists of p type aluminum $_{0.3}\text{Ga}_{0.7}\text{N}$  in which bandgap energy was large and  $\text{cm}^{-3}$  [  $1 \times 10^{20}$  ]-doped Mg rather than the active layer is grown up by 300-A thickness. Then, the p side light guide layer 18 which

bandgap energy becomes at 1050 \*\* from p type GaN smaller than the p side cap layer 17 to which Mg was  $\text{cm}^{-3}[1 \times 10^{20}]$ -doped is grown up by 0.1 micrometer of thickness.

[0079]Then, TMA, TMG, ammonia, and  $\text{Cp}_2\text{Mg}$  are used, The 1st layer that consists of p type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N which  $\text{cm}^{-3}[1 \times 10^{20}]$ -doped Mg at 1050 \*\* is grown up by 20-A thickness, Then, only TMA is stopped and the 2nd layer that consists of p type GaN which  $\text{cm}^{-3}[1 \times 10^{20}]$ -doped Mg is grown up by 20-A thickness. And this operation is repeated 100 times, respectively and the p side clad layer 19 which consists of superlattice layers of 0.4 micrometer of the total thickness is formed. The p side contact layer 20 which finally consists of p type GaN which  $\text{cm}^{-3}[2 \times 10^{20}]$ -doped Mg on the p side clad layer 19 at 1050 \*\* is grown up by 150-A thickness.

[0080]Temperature is lowered to a room temperature after ending reaction, among a nitrogen atmosphere, in a reaction vessel for a wafer, annealing is performed at 700 \*\* and a p type layer is low-resistance-ized further. As a wafer is picked out from a reaction vessel after annealing and it is shown in drawing 2, the p side contact layer 20 of the top layer and the p side clad layer 19 are etched with an RIE system, and it is considered as the ridge shape which has

the stripe width of 4 micrometers.

[0081]Next, as a mask is formed in the ridge surface and it is shown in drawing 2, it is made symmetrical to a ridge of stripe shape, and the surface of the n side contact layer 12 is exposed. Next, the p electrode 21 which consists of nickel and Au all over almost [ of the stripe ridge outermost surface of the p side contact layer 20 ] is formed. On the other hand, the n electrode 23 which consists of Ti and aluminum is formed all over almost [ of the n side contact layer 3 of stripe shape ].

[0082]Next, as shown in drawing 2, the insulator layer 25 which consists of  $\text{SiO}_2$  is formed in the surface of a nitride semiconductor layer exposed between the p electrode 21 and the n electrode 23, and the p pad electrode 22 electrically connected with the p electrode 21 via this insulator layer 25 and the n pad electrode 24 are formed. A wafer which formed n electrode and p electrode as mentioned above shall be transported to polish equipment, the silicon on sapphire 1 of a side which does not form a nitride semiconductor shall be wrapped using a diamond polishing agent, and thickness of a substrate shall be 50 micrometers. After wrapping, 1 micrometer is polished with still finer abrasive soap, and a substrate face is made into mirror finished surface form.



[0083]The scribe after substrate polish and of the polished surface side is carried out, cleavage is carried out to bar shape in a direction vertical to the electrode of stripe shape, and a resonator is produced to a cleavage plane. The dielectric multilayer which consists of SiO<sub>2</sub> and TiO<sub>2</sub> was formed in the resonator face, and finally, in the direction parallel to p electrode, the bar was cut and it was considered as the laser chip. Next, in [ when the chip was installed in the heat sink by face up (state which the substrate and the heat sink countered), wire bonding of each electrode was carried out and laser oscillation was tried at the room temperature ] a room temperature, With threshold current density 2.9 kA/cm<sup>2</sup> and the threshold voltage 4.4V, continuous oscillation with an oscillation wavelength of 405 nm was checked, and the life of 50 hours or more was shown.

[0084](Comparative example 1) n type GaN which did not grow up the 2nd buffer layer 112 and cm<sup>-3</sup>[ 1x10<sup>19</sup>]-doped Si for the n side contact layer 12 further on the other hand -- it being single, and 5 micrometers being grown up, and, 0.4 micrometer of n side clad layers 14 are grown up by the n type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N single which cm<sup>-3</sup>[ 1x10<sup>19</sup>]-doped Si, 0.4 micrometer of p side clad layers 19 are grown up by the p type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N single which 1-x-10<sup>-20</sup>-/-m<sup>-3</sup>-doped Mg, 0.2 micrometer of single p type GaN(s) which

furthermore  $\text{cm}^{-3}$  [ $2 \times 10^{20}$ ]-doped Mg for the p side contact layer 20 were grown up, and also the laser device was obtained like working example 1. That is, as basic constitution, as shown in Table 1, it constitutes.

[0085]

[Table 1]

基板	10・・・サファイア	
バッファ層	11・・・GaN	200Å
nコンタクト層	12・・・Siドープn型GaN Si: $1 \times 10^{19} / \text{cm}^3$	5 $\mu\text{m}$
クラッド防止層	13・・・Siドープn型In <sub>0.1</sub> Ga <sub>0.9</sub> N Si: $5 \times 10^{18} / \text{cm}^3$	500Å
nクラッド層	14・・・Siドープn型Al <sub>0.2</sub> Ga <sub>0.8</sub> N Si: $5 \times 10^{18} / \text{cm}^3$	0.5 $\mu\text{m}$
n光ガイド層	15・・・Siドープn型GaN Si: $5 \times 10^{18} / \text{cm}^3$	0.1 $\mu\text{m}$
活性層(MQW) (総膜厚175Å)	16・・・SiドープIn <sub>0.2</sub> Ga <sub>0.8</sub> N	25Å
	SiドープIn <sub>0.01</sub> Ga <sub>0.99</sub> N Si: $8 \times 10^{18} / \text{cm}^3$	50Å
キャップ層	17・・・Mgドープp型Al <sub>0.1</sub> Ga <sub>0.9</sub> N Mg: $1 \times 10^{20} / \text{cm}^3$	300Å
p光ガイド層	18・・・Mgドープp型GaN Mg: $1 \times 10^{20} / \text{cm}^3$	0.1 $\mu\text{m}$
pクラッド層	19・・・Mgドープp型Al <sub>0.2</sub> Ga <sub>0.8</sub> N Mg: $1 \times 10^{20} / \text{cm}^3$	0.5 $\mu\text{m}$
pコンタクト層	20・・・Mgドープp型GaN Mg: $2 \times 10^{20} / \text{cm}^3$	0.2 $\mu\text{m}$

[0086]Although continuous oscillation was checked by threshold current density 7 kA/cm<sup>2</sup> as for the laser device of the comparative example constituted in this way, threshold voltage has gone out in those or more [ 8.0 ] with V, and several minutes.

[0087][Working example 2] The 1st layer that consists the n side contact layer 12 of n type aluminum<sub>0.05</sub>Ga<sub>0.95</sub>N which cm<sup>-3</sup>[  $2 \times 10^{19}$ ]-doped Si in working example 1 is grown up by 30-A thickness, Then, the 2nd layer that consists of undoped GaN is grown up by 30-A thickness, this is repeated, and it is considered as the superstructure of 1.2 micrometers of the total thickness. When it was considered as the laser device which has the same structure as working example 1, it is threshold current density 2.7 kA/cm<sup>2</sup> and the threshold voltage 4.2V, and, as for the other structure, the life also showed 60 hours or more.

[0088][Working example 3] In working example 2, set the 2nd layer to GaN which cm<sup>-3</sup>[  $1 \times 10^{18}$ ]-doped Si in the superlattice which constitutes the n side contact layer 12, and also. When the laser device which has the same structure as working example 2 was produced, the laser device which has the characteristic almost equivalent to working example 2 was obtained.

[0089][Working example 4] In working example 1, set the 2nd buffer layer 112 to GaN which cm<sup>-3</sup>[  $1 \times 10^{17}$ ]-doped Si, and grow up it 4 micrometers, and also. When the laser device which has the same structure as working example 1 was produced, it went up to threshold current density 2.9 kA/cm<sup>2</sup> and the threshold voltage 4.5V, but the life showed 50 hours or more.

[0090][Working example 5] The 1st layer that consists the n side contact layer 12 of n type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N which cm<sup>-3</sup>[  $2 \times 10^{19}$ ]-doped Si in working example 1 is grown up by 60-A thickness, Then, the 2nd layer that consists of GaN which cm<sup>-3</sup>[  $1 \times 10^{19}$ ]-doped Si is grown up by 40-A thickness, this is repeated successively, and it is considered as the superstructure of 2 micrometers of the total thickness. And 0.4 micrometer of n side clad layers 14 are grown up by the n type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N single which cm<sup>-3</sup>[  $1 \times 10^{19}$ ]-doped Si. When it was considered as the laser device which has the same structure as working example 1, it is threshold current density 3.2 kA/cm<sup>2</sup> and the threshold voltage 4.8V, and, as for the other structure, the life also showed 30 hours or more.

[0091][Working example 6] As compared with working example 1, following (1) differs from (2), and also working example 6 is constituted like working example 1.

(1) Stop only TMG after buffer layer 11 growth, and raise temperature to 1050 \*\*. If it becomes 1050 \*\*, TMA, TMG, ammonia, and Silang will be used for material gas, The 1st layer that consists of n type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N which cm<sup>-3</sup>[  $1 \times 10^{19}$ ]-doped Si is grown up by 60-A thickness, then Silang and the 2nd layer that stops TMA and consists of undoped GaN are grown up by 40-A thickness. and

1st layer + 2nd layer + 1st layer + 2nd layer + ... as -- superlattice layers are constituted, respectively the 1st layer is laminated to 500 layers, the 2nd layer is laminated alternately [ 500 layer ], and the n side contact layer 12 which consists of superlattice of 5 micrometers of the total thickness is formed.

(2) Next, grow up the crack prevention layer 13 which consists of  $\text{In}_{0.1}\text{Ga}_{0.9}\text{N}$  which  $\text{cm}^{-3}$  [  $5 \times 10^{18}$  ]-doped Si like working example 1 by 500-Å thickness. And temperature shall be 1050 °C and the n side clad layer 14 which consists of n type  $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$  which  $\text{cm}^{-3}$  [  $5 \times 10^{18}$  ]-doped Si is grown up by 0.5 micrometer of thickness using TMA, TMG, ammonia, and Silang. Let tops be a laser device of working example 1, and a laser device which has the same structure from the next n side clad layer 14. That is, in the basic structure of Table 1, the n side contact layer 12 and the p side clad layer 19 are used as superlattice, and the laser device which makes 150 Å thickness of the p side contact layer 20 like working example 1 is produced. This laser device was threshold current density 3.2 kA/cm<sup>2</sup> and the threshold voltage 4.8V, 405-nm continuous oscillation was checked and the life also showed 30 hours or more.

[0092]When the thickness of p side contact layer of the LD element of the structure of working example 6 is changed one by one, the relation between the

thickness of the p side contact layer and the threshold voltage of an LD element is shown in drawing 3. p side contact layer this sequentially from the left A (10 Å or less), The threshold voltage in B (10 Å), C (30 Å), D (150 Å, this example), E (500 Å), F (0.2 micrometer), G (0.5 micrometer), and H (0.8 micrometer) is shown. As shown in this figure, when the thickness of p side contact layer exceeds 500 Å, threshold voltage is in the tendency to go up gradually. As for the thickness of the p side contact layer 20, it is still more preferably desirable that it is 300 Å or less 500 Å or less. Since the surface of the lower p side clad layer 19 will be exposed if it becomes 10 Å or less (2 atomic layers about 1 atomic layer, near), the contact resistance of p electrode worsens and threshold voltage tends to rise. However, in the LD element of this invention, since it has superlattice layers, threshold voltage is falling substantially compared with the thing of a comparative example.

[0093](Comparative example 2) The 1st layer that consists the n side clad layer 14 of n type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N which cm<sup>-3</sup>[ 1x10<sup>19</sup>]-doped Si in the laser device of the composition of Table 1 is grown up by 180-Å thickness, Then, the 2nd layer that consists of undoped GaN is grown up by 120-Å thickness, and let it be a multilayer film of 0.6 micrometer of the total thickness. That is, when it

constituted from structure which thickened thickness of the 1st layer and the 2nd layer and the laser device was produced, continuous oscillation was checked by threshold current density  $6.5 \text{ kA/cm}^2$ , and threshold voltage was  $7.5\text{V}$ . This laser device has gone out in several minutes.

[0094][Working example 7] The 1st layer that consists the p side clad layer 19 of aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N which  $\text{cm}^{-3}$  [ $1 \times 10^{20}$ ]-doped Mg, and  $60 \text{ \AA}$  in working example 6, It is considered as the superstructure of  $0.5 \text{ micrometer}$  of the total thickness that laminated p type GaN which  $\text{cm}^{-3}$  [ $1 \times 10^{20}$ ]-doped Mg, and the 2nd layer that consists of  $40 \text{ \AA}$ , and also the same laser device as working example 6 is produced. That is, when the thickness of the superlattice layers which constitute the p side clad layer 19 of working example 6 was changed and also the laser device was produced similarly, threshold voltage suited the tendency to go up a little as compared with the laser device of working example 6, but the life of 20 hours or more was shown.

[0095][Working example 8] The 1st layer that consists the n side clad layer 14 of n type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N which  $\text{cm}^{-3}$  [ $1 \times 10^{19}$ ]-doped Si, and  $60 \text{ \AA}$  further in working example 7, It is considered as the superstructure of  $0.5 \text{ micrometer}$  of the total thickness that laminated n type GaN which  $\text{cm}^{-3}$  [ $1 \times 10^{19}$ ]-doped Si,

and the 2nd layer that consists of 40 Å, and also the same laser device as working example 7 is produced. That is, the laser device which used the n side clad layer as superlattice in addition to the n side contact layer 12 of working example 6 and the p side clad layer 19 had the characteristic almost equivalent to working example 6.

[0096][Working example 9] In working example 1, without growing up the 2nd buffer layer 112, as shown in Table 1, 5 micrometers of n type GaN layers which  $\text{cm}^{-3}$  [ $1 \times 10^{19}$ ]-doped Si as the n side contact layer 12 directly on the 1st buffer layer 11 are grown up. Others are taken as the laser device which has the same structure as working example 1. That is, the 1st layer that consists the n side clad layer 14 of 20-Å Si ( $1 \times 10^{19}/\text{cm}^3$ ) doped n type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N in the basic structure of Table 1, It is considered as the superstructure of 0.4 micrometer of the total thickness that laminates the 2nd layer that consists of the 20-Å undoping GaN. The 1st layer that furthermore consists the p side clad layer 19 of 20-Å Mg ( $1 \times 10^{20}/\text{cm}^3$ ) doped p type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N, It is considered as the superstructure of 0.4 micrometer of the total thickness that laminates the 2nd layer that consists of the 20-Å Mg ( $1 \times 10^{20}/\text{cm}^3$ ) doped p type GaN. When the p side contact layer 20 is used as the 150-Å Mg ( $2 \times 10^{20}/\text{cm}^3$ ) doped p type GaN,



like working example 1 further again by threshold current density  $3.3 \text{ kA/cm}^2$ .  
405-nm continuous oscillation was checked and, as for threshold voltage, 5.0V  
and a life also showed 30 hours or more.

[0097][Working example 10] In working example 9, the 2nd layer that constitutes the superlattice of the n side clad layer 14 is set to GaN which  $\text{cm}^{-3}$   $[1 \times 10^{17}]$ -doped Si, and also the same laser device as working example 9 is produced. That is, the laser device which many Si was doped in the layer with larger bandgap energy, and also was produced like working example 9 in it showed the characteristic almost equivalent to working example 9.

[0098][Working example 11] In working example 9, the 2nd layer that constitutes the n side clad layer 14 is set to n type  $\text{In}_{0.01}\text{Ga}_{0.99}\text{N}$  which  $\text{cm}^{-3}$   $[1 \times 10^{19}]$ -doped Si, and also a laser device is produced similarly. That is, the laser device which set to InGaN the presentation of the 2nd layer that constitutes the superlattice of the n side clad layer 14, and impurity concentration of the 1st layer and the 2nd layer was made the same, and also was produced like working example 9 showed the characteristic almost equivalent to working example 9.

[0099][Working example 12] In working example 9, the thickness of the 1st layer (Si:  $1 \times 10^{19}/\text{cm}^3$  dope aluminum $_{0.2}\text{Ga}_{0.8}\text{N}$ ) that constitutes the n side clad layer 14

shall be 60 Å, The 2nd layer is set to 40-Å GaN which  $\text{cm}^{-3}$   $[1 \times 10^{19}]$ -doped Si, and is made into the superstructure of 0.5 micrometer of the total thickness. The thickness of the 1st layer (Mg:  $1 \times 10^{20}/\text{cm}^3$  dope aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N) that furthermore constitutes the p side clad layer 19 shall be 60 Å, The thickness of the 2nd layer (Mg:  $1 \times 10^{20} / \text{cm}^3$  dope: GaN) shall be 40 Å, and it is considered as the superstructure of 0.5 micrometer of the total thickness. That is, doped quantity of the 1st layer and the 2nd layer which constitutes the n side clad layer 14 is made the same, Change thickness, and change the thickness of the 1st layer and the 2nd layer which constitute the p side clad layer 19, and also. When the laser device was produced like working example 9, by threshold current density  $3.4 \text{ kA}/\text{cm}^2$ , 405-nm continuous oscillation was checked and, as for threshold voltage, 5.2V and a life also showed 20 hours or more.

[0100][Working example 13] The place which produced the laser device which Si concentration of the 2nd layer (GaN) that constitutes the n side clad layer 14 is made into  $1 \times 10^{17}/\text{cm}^3$  in working example 11, and also has the same structure as working example 11, The laser device which has the characteristic almost equivalent to working example 11 has been produced.

[0101][Working example 14] In working example 11, when the laser device

which the 2nd layer (GaN) that constitutes the n side clad layer 14 is made undoped, and also has the same structure as working example 11 was produced, the laser device which has the characteristic almost equivalent to working example 11 has been produced.

[0102][Working example 15] In working example 9, 0.4 micrometer of n side clad layers 14 are grown up by the n type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N single which cm<sup>-3</sup>[  $1 \times 10^{19}$ ]/-doped Si, and also a laser device is produced similarly. That is, the 1st layer that consists only the p side clad layer 19 of p type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N which cm<sup>-3</sup>[  $1 \times 10^{20}$ ]/-doped Mg like working example 1 in the basic structure of Table 1, It is considered as 20 Å and the superstructure of 0.4 micrometer of the total thickness that consists of 20 Å of the 2nd layer that consists of p type GaN which cm<sup>-3</sup>[  $1 \times 10^{19}$ ]/-doped Mg, When the p side contact layer 20 is used as the 150-Å Mg ( $2 \times 10^{20}$ /cm<sup>3</sup>) doped p type GaN like working example 1, similarly by threshold current density 3.4 kA/cm<sup>2</sup>. 405-nm continuous oscillation was checked, threshold voltage showed 5.1V and the life showed 20 hours or more.

[0103][Working example 16] In working example 15, the 1st layer (aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N) shall be 60 Å the thickness of the superlattice layers which constitute the p side clad layer 19, When laminated the 2nd layer (GaN) as 40 Å,

and it was considered as 0.5 micrometer of the total thickness and also the same laser device as working example 14 was obtained, threshold voltage suited the tendency to go up a little, but there were 20 hours or more of lives.

[0104][Working example 17] In working example 9, 0.4 micrometer of p side clad layers 19 are grown up by the p type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N single which cm<sup>-3</sup>[ 1x10<sup>20</sup>]/-doped Mg, and also a laser device is produced similarly. That is, the 1st layer that consists only the n side clad layer 14 of n type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N which cm<sup>-3</sup>[ 1x10<sup>19</sup>]/-doped Si like working example 1 in the basic structure of Table 1, It is considered as 20 Å and the superstructure of 0.4 micrometer of the total thickness that consists of 20 Å of the 2nd layer that consists of undoped GaN, When the p side contact layer 20 is used as the 150-Å Mg (2x10<sup>20</sup>/cm<sup>3</sup>) doped p type GaN like working example 1, similarly by threshold current density 3.5 kA/cm<sup>2</sup>. 405-nm continuous oscillation was checked, threshold voltage showed 5.4V and the life showed 10 hours or more.

[0105][Working example 18] In working example 17, the 1st layer (aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N) shall be 70 Å the thickness of the superlattice layers which constitute the n side clad layer 14, In<sub>0.01</sub>Ga<sub>0.99</sub>N which cm<sup>-3</sup>[ 1x10<sup>19</sup>]/-doped Si for the 2nd layer, When laminated as 70 Å, and it was considered as 0.49

micrometer of the total thickness and also the same laser device as working example 17 was obtained, compared with working example 16, threshold voltage suited the tendency to go up a little, but the laser device which similarly has a life of 10 hours or more was obtained.

[0106][Working example 19] In working example 17, the 1st layer (aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N) shall be 60 Å the thickness of the superlattice layers which constitute the n side clad layer 14, When laminated the 2nd layer (undoping GaN) as 40 Å, and it was considered as 0.5 micrometer of the total thickness and also the same laser device as working example 16 was obtained, compared with working example 17, threshold voltage suited the tendency to go up a little, but the laser device which similarly has a life of 10 hours or more was obtained.

[0107][Working example 20] In working example 9, it is considered as the 2nd layer that will be the 1st layer that consists the n side light guide layer 15 of undoped GaN further, and 20 Å from undoped In<sub>0.1</sub>Ga<sub>0.9</sub>N, and the superlattice layers of 800 Å of the total thickness that laminates 20. Besides, in addition, the p side light guide layer 18 is also made into the superstructure of 800 Å of the total thickness that laminates the 1st layer that consists of undoped GaN, 20 Å, and the 2nd layer that consists of undoped In<sub>0.1</sub>Ga<sub>0.9</sub>N, and 20 Å. That is, in the

basic structure of Table 1, the n side clad layer 14, the n side light guide layer 15, the p side light guide layer 18, and the p side clad layer 19 are made into a superstructure, When the p side contact layer 20 is used as the 150-A Mg ( $2 \times 10^{20}/\text{cm}^3$ ) doped p type GaN, like working example 1 further again by threshold current density 2.9 kA/cm<sup>2</sup>. 405-nm continuous oscillation was checked and, as for threshold voltage, 4.4V and a life also showed 60 hours or more.

[0108][Working example 21] This example is described based on the LED element of drawing 1. The buffer layer 2 which comes from GaN on the substrate 1 which consists of sapphire like working example 1 is grown up by 200-A thickness, Subsequently, the contact layer which consists of n type GaN which  $\text{cm}^{-3}$  [ $1 \times 10^{19}$ ]-doped Si is grown up by 5-micrometer thickness, and the active layer 4 which consists of single quantum well structure of 30 Å of thickness which consists of  $\text{In}_{0.4}\text{Ga}_{0.6}\text{N}$  next is grown up.

[0109]The 1st layer that consists of p type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N which  $\text{cm}^{-3}$  [ $1 \times 10^{20}$ ]-doped Mg like the (p side superlattice layers), next working example 1 is grown up by 20-Å thickness, Then, the 2nd layer that consists of p type GaN which  $\text{cm}^{-3}$  [ $1 \times 10^{19}$ ]-doped Mg is grown up by 20-Å thickness, and the p side clad layer 5 which consists of superlattice of 0.4 micrometer of the total thickness

is grown up. Although the thickness in particular of this p side clad layer 4 is not limited, either, it is desirable to make it grow up at 500 Å or more and 1 micrometer or less still more preferably 2 micrometers or less 100 Å or more.

[0110]Next, the p type GaN layer which cm<sup>-3</sup>[  $1 \times 10^{20}$  ]-doped Mg on this p side clad layer 5 is grown up by 0.5 micrometer of thickness. After growth, after picking out a wafer from a reaction vessel and performing annealing like working example 1, the surface of the n side contact layer 3 which should perform etching from the p side contact layer 6 side, and should form the n electrode 9 is exposed. The p electrode 7 of the translucency which consists of nickel-Au of 200 Å of thickness all over almost [ of the p side contact layer 6 of the top layer ] is formed, and the p pad electrode 8 which consists of Au(s) is formed on the whole surface electrode 7. The n electrode 9 which consists of Ti-aluminum is formed also in the surface of exposed n side contact layer.

[0111]When the wafer which formed the electrode as mentioned above was divided into the chip of a 350-micrometer angle and it was considered as the LED element, 520-nm green emission was shown in  $I_f 20\text{mA}$ , and  $V_f$  was 3.2V. On the other hand,  $V_f$  of the LED element which constituted the p side clad layer 5 from single Mg-dope aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N was 3.4V. Furthermore, in

electrostatic pressure-proofing, the direction of this example had electrostatic pressure-proofing of more than twice.

[0112][Working example 22] In working example 21, the superlattice layers which constitute the p side clad layer 5, The thickness of the 1st layer shall be 50 Å and the 2nd layer as GaN which  $\text{cm}^{-3}$  [ $1 \times 10^{20}$ ]-doped Mg, and 50 Å, 25 layers were laminated, respectively, and when it was considered as the superlattice of 0.25 micrometer of the total thickness and also the LED element was created similarly, the LED element which has the characteristic almost equivalent to working example 21 was obtained.

[0113][Working example 23] In working example 21, 100 Å of the 1st layer, and the 2nd layer for the thickness of the superlattice layers which constitute the p side clad layer 5 as 70-Å thickness, When it was considered as the superlattice of 0.25 micrometer of the total thickness and also the LED element was created similarly,  $V_f$  was 3.4V, but electrostatic pressure-proofing was superior to the conventional thing not less than 20%.

[0114][Working example 24] When growing up the n side contact layer 3 in working example 21, The 1st layer that consists of n type  $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$  which  $\text{cm}^{-3}$  [ $2 \times 10^{19}$ ]-doped Si 60 Å, The 2nd layer that consists of undoped



GaN is grown up by 40-A thickness, respectively the 1st layer is laminated to 500 layers, the 2nd layer is laminated alternately [ 500 layer ], and it is considered as the superlattice of 5 micrometers of the total thickness. When others produced the LED element like working example 12, similarly, in  $I_f 20\text{mA}$ ,  $V_f$  fell to 3.1V, and comparison comparison was carried out and it acted to 2.5 or more times as Kougami of the electrostatic pressure-proofing at the former.

[0115][Working example 25] In working example 23, the thickness of the 1st layer (aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N) of the superlattice which constitutes the p side clad layer 5 shall be 60 Å, and the thickness of the 2nd layer shall be 40 Å, When the LED element which laminate alternately [ 25 layer ], respectively, and it is considered as 0.3 micrometer of the total thickness, and also has the same structure was produced,  $V_f$  was 3.2V and electrostatic pressure-proofing was more than twice over the past.

[0116][Working example 26] This example is described based on the laser device shown in drawing 4. Although it is a sectional view at the time of drawing 4 as well as drawing 2 cutting an element in a direction vertical to the resonant direction of a laser beam, A different place from drawing 2 is one of the place which uses the substrate 101 which turns into the substrate 10 from GaN, and

the places into which the 3rd buffer layer 113 that doped the n type impurity is grown up without growing up the 2nd buffer layer 112. The laser device shown in this drawing 4 is obtained by the following methods.

[0117]MOVPE method or the HVPE method is first used on silicon on sapphire, after growing up the GaN layer which  $\text{cm}^{-3}$  [  $5 \times 10^{18}$  ]-doped Si at 300 micrometers in thickness, silicon on sapphire is removed and the 300-micrometer-thick Si-dope GaN board 101 is produced. The GaN board 101 is obtained by removing the different-species board, after making it grow up by not less than 100-micrometer thickness on a different substrate in this way from a nitride semiconductor for example. Undoping may be sufficient as the GaN board 101, and it may dope and produce a n type impurity. If it usually dopes an impurity in the range of  $1 \times 10^{17}/\text{cm}^3$  -  $1 \times 10^{19}/\text{cm}^3$  in doping a n type impurity, a good crystalline GaN board will be obtained.

[0118]Temperature shall be 1050 \*\* after GaN board 101 production, and the 3rd buffer layer 113 that consists of n type GaN which  $\text{cm}^{-3}$  [  $3 \times 10^{18}$  ]-doped Si is grown up by 3-micrometer thickness. Although the 3rd buffer layer 113 is a layer which is equivalent to the n side contact layer 14 in drawing 1 and drawing 2, since it is not a layer which forms an electrode, it does not call it a contact layer

here, but calls it the 3rd buffer layer 113. Although the 1st buffer layer grown up at low temperature like working example 1 between the GaN board 101 and the 3rd buffer layer 113 may be grown up, when growing up the 1st buffer layer, it is desirable to use 300 Å or less.

[0119]Next, the crack prevention layer 13 which consists of  $\text{In}_{0.1}\text{Ga}_{0.9}\text{N}$  which  $\text{cm}^{-3}$   $[5 \times 10^{18}]$ -doped Si like working example 1 on the 3rd buffer layer 113 is grown up by 500-Å thickness. Next, the 1st layer and 20 Å which consists of n type aluminum $_{0.2}\text{Ga}_{0.8}\text{N}$  which  $\text{cm}^{-3}$   $[5 \times 10^{18}]$ -doped Si, The n side clad layer 14 which consists of superlattice layers of 0.4 micrometer of the total thickness which laminated alternately 20 Å of the 2nd layer that consists of GaN which  $\text{cm}^{-3}$   $[5 \times 10^{18}]$ -doped Si 100 times is grown up. Next, the n side light guide layer 15 which consists of n type GaN which  $\text{cm}^{-3}$   $[5 \times 10^{18}]$ -doped Si like working example 1 is grown up by 0.1 micrometer of thickness.

[0120]Next, the well layer and 25 Å which consists of undoping  $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ , 50 Å of barrier layers which consist of the undoping GaN are grown up, and the active layer 16 of the multiple quantum well structure (MQW) of 175 Å of the total thickness that finally laminated the well layer is grown up twice repeatedly by turns.

[0121]Next, the p side cap layer 17 which consists of p type aluminum<sub>0.3</sub>Ga<sub>0.7</sub>N which cm<sup>-3</sup>[ 1x10<sup>20</sup>]-doped Mg like working example 1 is grown up by 300-A thickness, The p side light guide layer 18 which consists of p type GaN which cm<sup>-3</sup>[ 1x10<sup>20</sup>]-doped Mg is grown up by 0.1 micrometer of thickness.

[0122]Next, the 1st layer and 20 A which consists of p type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N which cm<sup>-3</sup>[ 1x10<sup>20</sup>]-doped Mg like working example 1, The 2nd layer that consists of p type GaN which cm<sup>-3</sup>[ 1x10<sup>20</sup>]-doped Mg, The p side clad layer 19 which consists of superlattice layers of 0.4 micrometer of the total thickness which consist of 20 A is formed, The p side contact layer 20 which finally consists of p type GaN which cm<sup>-3</sup>[ 2x10<sup>20</sup>]-doped Mg on the p side clad layer 19 is grown up by 150-A thickness.

[0123]After ending reaction and after carrying out annealing at 700 \*\*, like working example 1, the p side contact layer 20 of the top layer and the p side clad layer 19 are etched with an RIE system, and it is considered as the ridge shape which has the stripe width of 4 micrometers.

[0124]Next, the p electrode 21 which consists of nickel and Au as well as working example 1 all over almost [ of the stripe ridge outermost surface of the p side contact layer 20 ] is formed, and the n electrode 23 which consists of Ti and

aluminum is formed all over almost [ of the rear face of the GaN board 101 ].

[0125]Next, as shown in drawing 4, the insulator layer 25 which consists of SiO<sub>2</sub> of the p side clad layer 19 excluding the area of the p electrode 21 is formed, and the p pad electrode 22 electrically connected with the p electrode 21 is formed via this insulator layer 25.

[0126]Cleavage of the GaN board 101 is carried out to bar shape in a direction vertical to the p electrode 21 after electrode formation, and a resonator is produced to a cleavage plane. The cleavage plane of a GaN board is made into M side. The dielectric multilayer which consists of SiO<sub>2</sub> and TiO<sub>2</sub> was formed in the cleavage plane, and it was considered as the laser chip which cuts a bar and is finally shown in drawing 4 in a direction parallel to p electrode. Next, in [ when the chip was installed in the heat sink by face up (state which the substrate and the heat sink countered), wire bonding of the p pad electrode 22 was carried out and laser oscillation was tried at the room temperature ] a room temperature, With threshold current density 2.5 kA/cm<sup>2</sup> and the threshold voltage 4.0V, continuous oscillation with an oscillation wavelength of 405 nm was checked, and the life of 500 hours or more was shown. By having used GaN for the substrate, this is because the breadth of the crystal defect decreased.

[0127]

[Effect of the Invention]As explained above, since the nitride semiconductor device concerning this invention is constituted using superlattice layers, it can improve power efficiency extremely in p type nitride semiconductor fields or n type nitride semiconductor fields other than an active layer. That is, although making an active layer into multiple quantum well structure was proposed in the conventional nitride semiconductor device, the active layer was inserted, for example, usually cladding layers comprised a single nitride semiconductor layer. However, in the nitride semiconductor device of this invention, since the superlattice layers which have the layer that a quantum effect appears are provided as a cladding layer or a contact layer which pours in current, resistivity by the side of a cladding layer can be made low. By this, the threshold current of an LD element and threshold voltage can be made low, for example, and this element can be made long lasting. Although the further conventional LED was weak to static electricity, in this invention, an element strong against electrostatic pressure-proofing is realizable. Thus, since  $V_f$  and threshold voltage are made low, calorific value can also decrease and the reliability of this element can also be raised. According to the nitride semiconductor device of this invention, not to

mention light emitting devices, such as LED and LD, when it uses for a solar cell, a photosensor, a transistor, etc. which used the nitride semiconductor, it becomes possible to realize a device with high efficiency of an emergency, and the industrial utility value is dramatically large.

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## TECHNICAL FIELD

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[Field of the Invention] This invention Light emitting devices, such as LED (light emitting diode) and LD (laser diode), It is related with the element which consists of a nitride semiconductor ( $\text{In}_x\text{Al}_y\text{Ga}_{1-x-y}\text{N}$ ,  $0 \leq x$ ,  $0 \leq y$ ,  $x+y \leq 1$ ) used for electron devices, such as photo detectors, such as a solar cell and a photosensor, or a transistor. a layer which general formula  $\text{In}_x\text{Ga}_{1-x}\text{N}$ ,  $\text{aluminum}_y\text{Ga}_{1-y}\text{N}$ , etc. which are used in this Description only show the empirical formula of a nitride semiconductor layer, and is different -- for example, even if shown by the same general formula, It is not shown till the X value of those layers and Y value being in agreement.

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## PRIOR ART

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[Description of the Prior Art]The nitride semiconductor was just put in practical use with a full color LED display, a traffic signal, etc. as a material of high-intensity blue LED and authentic green LED recently. LED used for these various devices has terrorism structure to the double into which the active layer which consists of InGaN of single quantum well structure (SQW:Single-Quantum- Well) between a n type nitride semiconductor layer and a p type nitride semiconductor layer was inserted. Wavelength, such as blue and green, is determined by fluctuating In composition ratio of an InGaN active layer.

[0003]These people announced the 410-nm laser oscillation in the room temperature for the first time under pulse current in the world recently using this material (for example, Jpn.J.Appl.Phys. Vol35 (1996) pp.L74-76). This laser device is the conditions of 2 microseconds of pulse width, and 2 ms of pulse cycles, and shows the threshold current of 610 mA, threshold current density 8.7 kA/cm<sup>2</sup>, and a 410-nm oscillation. The threshold current announced the improved low laser device further again in Appl.Phys.Lett., Vol.69, No.10, 2 Sep. 1996, and p.1477-1479. This laser device has the structure where the ridge



stripe was formed in a part of p type nitride semiconductor layer.

1 microsecond of pulse width, 1 ms of pulse cycles, and 0.1% of duty ratio show the threshold current of 187 mA, threshold current density 3 kA/cm<sup>2</sup>, and a 410-nm oscillation.

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## EFFECT OF THE INVENTION

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[Effect of the Invention]As explained above, since the nitride semiconductor device concerning this invention is constituted using superlattice layers, it can improve power efficiency extremely in p type nitride semiconductor fields or n type nitride semiconductor fields other than an active layer. That is, although making an active layer into multiple quantum well structure was proposed in the conventional nitride semiconductor device, the active layer was inserted, for example, usually cladding layers comprised a single nitride semiconductor layer. However, in the nitride semiconductor device of this invention, since the superlattice layers which have the layer that a quantum effect appears are provided as a cladding layer or a contact layer which pours in current, resistivity

by the side of a cladding layer can be made low. By this, the threshold current of an LD element and threshold voltage can be made low, for example, and this element can be made long lasting. Although the further conventional LED was weak to static electricity, in this invention, an element strong against electrostatic pressure-proofing is realizable. Thus, since  $V_f$  and threshold voltage are made low, calorific value can also decrease and the reliability of this element can also be raised. According to the nitride semiconductor device of this invention, not to mention light emitting devices, such as LED and LD, when it uses for a solar cell, a photosensor, a transistor, etc. which used the nitride semiconductor, it becomes possible to realize a device with high efficiency of an emergency, and the industrial utility value is dramatically large.

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## TECHNICAL PROBLEM

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[Problem to be solved by the invention]The blue and green LED which consist of nitride semiconductors are forward current ( $I_f$ )20mA, and compared with red LED which forward voltage ( $V_f$ ) becomes from the semiconductor of 3.4V - those with 3.6V, and a GaAlAs system, as for more than 2V, since it is high, a fall of

further  $V_f$  is desired. In LD, the current in a threshold value and voltage are still high, and in order to carry out continuous oscillation at a room temperature, it is necessary to realize the element that this threshold current and voltage fall and that power efficiency is still higher.

[0005]Therefore, by reducing the current in the threshold value of the LD element which mainly consists of nitride semiconductors, and voltage, the place made into the purpose of this invention realizes continuous oscillation, and reduces  $V_f$  in a LED element, is reliable, and there is in realizing the nitride semiconductor device excellent in power efficiency.

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## MEANS

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[Means for solving problem]As a result of examining a nitride semiconductor device wholeheartedly that the p type layer which sandwiched the active layer, and/or a n type layer should be improved, this invention persons by using superlattice layers for the p type layer except an active layer, and/or a n type layer, The crystallinity of the layer using superlattice layers can be made good, and it newly finds out that said problem is solvable, and came to accomplish this invention.

[0007]Namely, the 1st nitride semiconductor device concerning this invention,

The n type nitride semiconductor layer field where n side contact layer, the n side clad layer, and the n side light guide layer were laminated on the substrate,

It is a nitride semiconductor device which has the p type nitride semiconductor layer field where the active layer which consists of nitride semiconductors, the p side light guide layer and a p side clad layer, and p side contact layer were laminated, The 1st layer that consists of a nitride semiconductor which said p side clad layer has thickness of 100A or less at not less than 10A, and does not contain aluminum, A presentation differs from this 1st layer, and it has thickness of 100A or less at not less than 10A, and the 2nd layer that consists of a nitride semiconductor containing aluminum is characterized by being the laminated superlattice layers. Since the resistance of the p type nitride semiconductor layer which consists of said superlattice layers can be made very low by this, power efficiency of a nitride semiconductor device can be made high. In the 1st nitride semiconductor device concerning this invention, said superlattice layers, Since the 2nd layer that consists of a nitride semiconductor which the 1st layer, this 1st layer, and presentation which consist of a nitride semiconductor which has thickness of 100A or less differ from each other, and has thickness of 100A or

less is laminated, the crystallinity of said superlattice layers can improve. the threshold current by applying a superstructure to a p type cladding layer, and voltage -- it seems to be low -- \*\*\*\*\* can be large and a threshold current and voltage can be notably reduced in this invention.

[0008]It is preferred to dope a p type impurity in the 1st nitride semiconductor device concerning this invention in either [ at least ] said 1st layer or said 2nd layer, and, as for the concentration of the p type impurity doped by said 1st layer and said 2nd layer, differing mutually is preferred. When the bandgap energy of said 1st layer and said 2nd layer differs mutually in the 1st nitride semiconductor device of the above, it is preferred that bandgap energy enlarges impurity concentration of a large layer.

[0009]The 2nd nitride semiconductor device concerning this invention, The n type nitride semiconductor layer field where n side contact layer, the n side clad layer, and the n side light guide layer were laminated on the substrate, It is a nitride semiconductor device which has the p type nitride semiconductor layer field where the active layer which consists of nitride semiconductors, the p side light guide layer and a p side clad layer, and p side contact layer were laminated, Among said p side clad layer and said n side clad layer, at least one. It has

thickness of 100Å or less at not less than 10Å, and a presentation differs from the 1st layer that consists of a nitride semiconductor which does not contain aluminum, and this 1st layer, and it has thickness of 100Å or less at not less than 10Å, and the 2nd layer that consists of a nitride semiconductor containing aluminum is characterized by being the laminated superlattice layers.

[0010]In the 2nd nitride semiconductor device concerning this invention, when said p side clad layers are said superlattice layers, It is preferred to dope a p type impurity in either [ at least ] said 1st layer or said 2nd layer, and, as for the concentration of the p type impurity doped by said 1st layer and said 2nd layer, differing mutually is preferred. When the bandgap energy of said 1st layer and said 2nd layer differs mutually in the 2nd nitride semiconductor device concerning this invention, it is preferred that bandgap energy enlarges impurity concentration of a large layer.

[0011]In the 2nd nitride semiconductor device concerning this invention, when said n side clad layers are said superlattice layers, It is preferred to dope a n type impurity in either [ at least ] said 1st layer or said 2nd layer, and it is preferred that the concentration of the n type impurity doped without the 1st layer of an account and said 2nd layer differs mutually. Under the present

circumstances, when the bandgap energy of said 1st layer and said 2nd layer differs mutually, it is preferred that bandgap energy enlarges impurity concentration of a large layer.

[0012]The 3rd nitride semiconductor device concerning this invention, The n type nitride semiconductor layer field where n side contact layer, the n side clad layer, and the n side light guide layer were laminated on the substrate, It is a nitride semiconductor device which has the p type nitride semiconductor layer field where the active layer which consists of nitride semiconductors, the p side light guide layer and a p side clad layer, and p side contact layer were laminated, The 1st layer that consists of a nitride semiconductor with which said n side clad layer has thickness of 100Å or less at not less than 10Å, and does not contain aluminum, A presentation differs from this 1st layer, and it has thickness of 100Å or less at not less than 10Å, The 3rd layer that consists of a nitride semiconductor which the 2nd layer that consists of a nitride semiconductor containing aluminum is the laminated superlattice layers, and said p side clad layer has thickness of 100Å or less at not less than 10Å, and does not contain aluminum, A presentation differs from this 3rd layer, and it has thickness of 100Å or less at not less than 10Å, and the 4th layer that consists of a nitride

semiconductor containing aluminum is characterized by being the laminated superlattice layers.

[0013]It may be made to form a Mine-like ridge part in a resonant direction in the 3rd nitride semiconductor device of the above in the layer currently formed above said p side clad layer and this p side clad layer.

[0014]In the 1st concerning this invention - the 3rd nitride semiconductor device, said active layer may have a nitride semiconductor containing indium. Said 1st [ the ] - the 3rd nitride semiconductor device, It may be made to form on C side of silicon on sapphire, and after said 1st [ the ] - the 3rd nitride semiconductor device grow up the GaN layer which doped Si on C side of silicon on sapphire, it may be made to form them on the GaN board from which silicon on sapphire was removed. In said 1st [ the ] - the 3rd nitride semiconductor device, said n side light guide layer may be GaN, and may be InGaN. In said 1st [ the ] - the 3rd nitride semiconductor device, said p side light guide layer may be GaN, and may be InGaN. Said active layer is touched in said 1st [ the ] - the 3rd nitride semiconductor device, It is preferred to provide the p side light guide layer in which bandgap energy is smaller than said p side cap layer in the position which has the p side cap layer which consists of a nitride semiconductor containing



aluminum, and is separated from an active layer rather than the p side cap layer.

[0015]The 1st layer that consists superlattice layers of  $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0 \leq x \leq 1$ ) in

the 1st - the 3rd nitride semiconductor device of this invention, If constituted by

laminating the 2nd layer that consists of aluminum $_{\gamma}\text{Ga}_{1-\gamma}\text{N}$  ( $0 \leq \gamma \leq 1$ ,  $x=\gamma \neq 0$ ),

General formula aluminum $_{\gamma}\text{Ga}_{1-\gamma}\text{N}$ - Since a good crystalline semiconductor layer is obtained, the nitride

semiconductor expressed with  $\gamma\text{N}$  and  $\text{In}_x\text{Ga}_{1-x}\text{N}$  can form a layer with few crystal defects.

Thereby, the crystallinity of the whole nitride semiconductor becomes good, and

when improvement (improvement in power efficiency) and this element are a

LED element or an LD element about the output of this element,  $V_f$ , a threshold

current, voltage, etc. can be made low. In the 1st of this invention - the 3rd nitride

semiconductor device. In said superlattice layers in order to form a layer with still

few crystal defects, It is still more preferred that said 1st layer consists of a

nitride semiconductor expressed with formula  $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0 \leq x < 1$ ), and said 2nd

layer consists of a nitride semiconductor expressed with formula

aluminum $_{\gamma}\text{Ga}_{1-\gamma}\text{N}$  ( $0 < \gamma < 1$ ).

[0016]In the 1st - the 3rd nitride semiconductor device of this invention, although

it is preferred that it is 70Å or less as mentioned above as for the thickness of

said 1st layer and the 2nd layer, it is set as 40Å or less still more preferably. In

this invention, the thickness of said 1st layer and the 2nd layer is set as not less than 10Å. By setting up within the limits of this, nitride semiconductor layers, such as aluminum<sub>Y</sub>Ga<sub>1-Y</sub>N (0< Y≤1) which was hard to grow up, can form with sufficient crystallinity by the former. Of the p type nitride semiconductor layers which are between p electrode and an active layer especially, at least further, And/or, when making into superlattice layers at least one layer in the n type nitride semiconductor layer between n side contact layer as a current injection layer and the active layer in which n electrode is formed, the effect by setting the 1st layer that constitutes the superlattice layers, and the 2nd layer as said thickness is large.

[0017]In the 1st - the 3rd nitride semiconductor device of this invention, it is preferred to have p side contact layer for forming p electrode, and to set the thickness of these p side contact layers as 500Å or less. Thus, the resistance of the thickness direction of these p side contact layers can be lowered by forming p side contact layer thinly. It is still more preferred to set it as 300Å or less in this invention. As for the minimum of the thickness of these p side contact layers, it is preferred to set it as not less than 10Å so that the semiconductor layer under this p type contact layer may not be exposed.

[0018]moreover -- forming the 1st buffer layer on a substrate and forming on it the 2nd buffer layer that consists of a nitride semiconductor of 0.1 micrometers or more of thickness in this invention, -- this -- it is preferred to form n side contact layer which consists of a nitride semiconductor with which a n type impurity was doped on the 2nd buffer layer. By this, carrier concentration can form good large crystalline n side contact layer. In order to form said 2nd buffer layer with still more sufficient crystallinity, it is preferred that impurity concentration of said 2nd buffer layer is low concentration as compared with said n side contact layer.

[0019]In this invention, as an impurity which determines a conductivity type, the [ which is doped by nitride semiconductor / periodic table ] -- the [ 4A fellows, 4B fellows, and ] -- the [ 6A fellows and ] -- there are a n type impurity belonging to 6B fellows and a p type impurity belonging to 1A, 1B fellows, 2A fellows, and 2B fellows (this Description is hereafter described as a n type impurity and a p type impurity suitably.). As mentioned above, when bandgap energy differs in the 1st layer and 2nd layer, it is desirable to enlarge impurity concentration of a layer with larger bandgap energy. By this, a high increase in power by an abnormal-conditions dope at the time of forming superlattice layers in the p type

nitride semiconductor layer side is expectable. In this invention, n side contact layers may be superlattice layers. Bandgap energy can differ mutually in two layers which constitute superlattice layers which are n side contact layers, and power efficiency can be raised by enlarging impurity concentration of a layer with larger bandgap energy by an effect which was similar to HEMT mentioned later. For example, in a laser device, it is in threshold voltage and a tendency for a threshold current to fall, further.

[0020]

[Mode for carrying out the invention] Hereafter, a nitride semiconductor device of an embodiment which starts this invention with reference to Drawings is explained.

Embodiment 1. drawing 1 is structure of a nitride semiconductor device of Embodiment 1 concerning this invention a shown typical sectional view, and this nitride semiconductor device, As a fundamental structure, on the substrate 1 which consists of sapphire, The buffer layer 2 which consists of GaN(s), the n side contact layer 3 which consists of Si-dope n type GaN, the active layer 4 which consists of InGaN of single quantum well structure, the p side clad layer 5 which consists of superlattice layers by which the 1st layer that differs in a

presentation mutually, and the 2nd layer were laminated, The p side contact layer 6 which consists of Mg doped GaN is the LED element laminated in order. In a nitride semiconductor device of Embodiment 1, all over almost [ of the p side contact layer 6 surface ], The whole surface electrode 7 of translucency is formed, the p electrode 8 for bonding is formed in the surface of the whole surface electrode 7, and the n electrode 9 is formed in the surface of the n side contact layer 2 further exposed from the p side contact layer 6 by carrying out etching removal of a part of nitride semiconductor layer.

[0021]The 1st layer of 30 Å of thickness (A) which consists of  $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0 \leq x \leq 1$ ) in which the nitride semiconductor device of Embodiment 1 doped Mg, for example as a p type impurity here, Since it has the p side clad layer 5 which has the low resistance which comprised superlattice layers by which the 2nd layer of 30 Å of thickness which consists of p type aluminum $_Y$ Ga $_{1-Y}$ N ( $0 \leq Y \leq 1$ ) which similarly doped Mg in the 1st layer and takes doses as a p type impurity was laminated,  $V_f$  can be made low. Thus, when forming superlattice layers in the p layer side, it is considered as the superlattice layers which dope p type impurities, such as Mg, Zn, Cd, and Be, in the 1st layer and/or the 2nd layer, and have a p type conductivity type. as laminating order -- the -- the [ 1+ ] -- the

[ 2+the 1st ... or, and ] -- the [ 2+ ] -- the order of 1+the 2nd ... may be sufficient, and at least a total of two or more layers are laminated.

[0022]The 1st layer and 2nd layer that consist of a nitride semiconductor which constitutes superlattice layers, It is not necessarily limited to the layer which consists of the layer and aluminum<sub>Y</sub>Ga<sub>1-Y</sub>N (0<=Y<=1) which consist of In<sub>X</sub>Ga<sub>1-X</sub>N (0<=X<=1), and what is necessary is just to comprise a nitride semiconductor with which presentations differ mutually. The bandgap energy of the 1st layer and the 2nd layer may differ, or it may be the same. For example, if the 1st layer is constituted from In<sub>X</sub>Ga<sub>1-X</sub>N (0<=X<=1) and the 2nd layer is constituted from aluminum<sub>Y</sub>Ga<sub>1-Y</sub>N (0< Y<=1), the bandgap energy of the 2nd layer will certainly become larger than the 1st layer, but. If the 1st layer is constituted from In<sub>X</sub>Ga<sub>1-X</sub>N (0<=X<=1) and the 2nd layer is constituted from In<sub>Z</sub>Al<sub>1-Z</sub>N (0< Z<=1), bandgap energy may be the same although the 1st layer and 2nd layer differ in a presentation. If the 1st layer is constituted from aluminum<sub>Y</sub>Ga<sub>1-Y</sub>N (0<=Y<=1) and the 2nd layer is constituted from In<sub>Z</sub>Al<sub>1-Z</sub>N (0< Z<=1), bandgap energy may be the same although the 1st layer and 2nd layer differ in a presentation similarly. That is, as long as this invention is superlattice layers which have the operation mentioned later, its bandgap energy of the 1st

layer and the 2nd layer may be the same, or they may differ. As mentioned above, since [ which differs in a presentation ] a film is laminated extremely and the thickness of each layer is thin enough, the superlattice layers said here are large concepts which say the thing of the layer laminated without the defect accompanying a stacking fault occurring, and include quantum well structure.

Although these superlattice layers do not have a defect inside, since they have the distortion accompanying a stacking fault, they are also usually called a strained super lattice. In this invention, even if V group elements, such as As and P, replace a part of N (nitrogen) of the 1st layer and the 2nd layer, as long as N exists, it is contained in a nitride semiconductor.

[0023]In this invention, the thickness of the 1st layer and the 2nd layer which constitutes superlattice layers, Since the 1st layer and 2nd layer will serve as thickness beyond an elastic strain limit and a very small crack or a crystal defect will enter easily into this film if thicker than 100 Å, it is preferred to set it as thickness of 100 Å or less. The minimum in particular of the thickness of the 1st layer and the 2nd layer is not limited, but should just be one or more atomic layers. However, in this invention the thickness of the 1st layer and the 2nd layer, The critical (elastic strain) marginal thickness of a nitride semiconductor is not

fully reached as it is 100 Å, It is most preferred for setting it as 70 Å or less to set up desirable still more desirable more thinly, in order to use below elastic strain marginal thickness and to lessen the crystal defect of a nitride semiconductor more, and to set it as 40 Å - 10 Å. Although it may be set as 10 Å or less (one atomic layer or two atomic layers) in this invention, if it is set as 10 Å or less, For example, as for the thickness of the 1st layer and the 2nd layer, since formation time and time and effort are taken on \*\* more than which the number of laminations increases, and a manufacturing process when forming the cladding layer of thickness of 500 Å or more by superlattice layers, it is preferred to set up more thickly than 10 Å.

[0024]In the case of the nitride semiconductor device of this Embodiment 1 shown in drawing 1, the p type clad layer 5 which consists of superlattice layers is formed between the active layer 4 and the p side contact layer 6 which is current injection layers, and is acting as a carrier confining layer. Thus, to make especially superlattice layers into a carrier confining layer, it is necessary to make average bandgap energy of superlattice layers larger than an active layer. In a nitride semiconductor, since the nitride semiconductor containing aluminum, such as AlN, AlGa<sub>N</sub>, and InAlN, has comparatively big bandgap energy, these



layers are used as a carrier confining layer. However, if a thick film is grown up by an AlGa<sub>N</sub> single like before, it has the character in which a crack enters easily into crystal growth.

[0025] Then, the nitride semiconductor which contains aluminum at least in this invention for either [ at least ] the 1st layer of superlattice layers, or the 2nd layer, By forming aluminum<sub>Y</sub>Ga<sub>1-Y</sub>N (0< Y<=1) by the thickness below an elastic strain limit preferably, and constituting superlattice layers, growth formation of the good crystalline superlattice layers is carried out very much, and bandgap energy forms the layer big moreover with few cracks. In this case, it is made hard to act also as a buffer layer at the time of growing up the 2nd layer that consists of a nitride semiconductor containing aluminum, if the nitride semiconductor layer which does not contain aluminum in the 1st layer is grown up by thickness of 100 Å or less still more preferably, and to go into the 2nd layer in a crack. Therefore, even if it laminates the 1st layer and 2nd layer, good crystalline superlattice layers without a crack can be formed. Therefore, in this Embodiment 1, it is preferred to use superlattice layers as the 1st layer (the 2nd layer) that consists of In<sub>X</sub>Ga<sub>1-X</sub>N (0<=X<=1), and the 2nd layer (the 1st layer) that consists of aluminum<sub>Y</sub>Ga<sub>1-Y</sub>N (0<=Y<=1, X!=Y=0).

[0026]In the nitride semiconductor device of this Embodiment 1, in order to adjust carrier concentration to at least one layer of the 1st layer and the 2nd layer which constitute the p side clad layer 5 which is superlattice layers, it is preferred that the p type impurity which sets the conductivity type of this layer as a p type is doped. Dope \*\* is also good by the concentration in which the 1st layer differs from the 2nd layer when doping a p type impurity in the 1st layer and 2nd layer, and when the bandgap energy of the 1st layer and the 2nd layer differs, it is still more desirable for bandgap energy to make the big layer high concentration. It is because the carrier concentration of one layer can become high substantially and the resistance of the whole superlattice layers can be reduced according to the quantum effect by abnormal-conditions doping, if an impurity is doped by concentration which is different in the 1st layer and the 2nd layer, respectively. Thus, in this invention, an impurity may be doped by different concentration in both the 1st layer and the 2nd layer, respectively, and an impurity may be doped in the 2nd either one of 1st layer or layer.

[0027]The impurity concentration doped by the 1st layer and 2nd layer, Although this invention in particular is not limited to this, usually with a p type impurity  $1 \times 10^{16}/\text{cm}^3$  -  $1 \times 10^{22}/\text{cm}^3$ , It is still more preferably desirable  $1 \times 10^{17}/\text{cm}^3$  -  $1 \times 10^{21}/\text{cm}^3$ ,

and to adjust to the range of  $1 \times 10^{18}/\text{cm}^3$  -  $2 \times 10^{20}/\text{cm}^3$  most preferably. It is because it is in the tendency for the crystallinity of superlattice layers to worsen when more [ if less than  $1 \times 10^{16}/\text{cm}^3$ , the effect of reducing  $V_f$  and threshold voltage will be hard to be acquired, and ] than  $1 \times 10^{22}/\text{cm}^3$ . It is desirable to also adjust a n type impurity to the same range. The Reason is the same.

[0028]However, in this invention, the impurity which determines a conductivity type as the 1st layer and 2nd layer does not need to be doped by superlattice layers. The superlattice layers by which this impurity is not doped may be which layers between an active layer and a substrate, as long as they are n type nitride semiconductor layer fields, and on the other hand, as long as they are p type nitride semiconductor layer fields, they may be which layers between a carrier confining layer (optical confinement layer) and an active layer.

[0029]Since the 1st layer and the 2nd layer are made into the thickness below an elastic strain limit, are laminated and the superlattice layers constituted as mentioned above form them, the lattice defect of a crystal can be reduced, and they can decrease a very small crack, and can improve crystallinity fast. As a result, without spoiling crystallinity not much, increase doped quantity of an impurity for it and by this. Since it can move without being able to make the

carrier concentration of a n type nitride semiconductor layer and a p type nitride semiconductor layer increase, and scattering about these carriers according to a crystal defect, as compared with the nitride semiconductor of a p type or a n type which does not have a superstructure, single or more figures resistivity can be made low.

[0030]Therefore, in the nitride semiconductor device (LED element) of this Embodiment 1. Obtaining a low resistance nitride semiconductor layer conventionally forms the p type clad layer 5 by the side of difficult p layer (p type semiconductor layer field (field which consists of the p type clad layer 5 and the p type contact layer 6)) using superlattice layers, By making low the resistance of this p type clad layer 5,  $V_f$  can be made low. That is, compared with a n type nitride semiconductor, resistivity is usually high [ a p type nitride semiconductor / a p type crystal is a semiconductor which is very hard to be obtained, and ], even if a p type nitride semiconductor is obtained double or more figures. Therefore, by forming p type superlattice layers in the p layer side, the p type layer which comprised superlattice layers can be extremely made into low resistance, and the fall of  $V_f$  appears notably. in order to obtain a p type crystal conventionally, annealing of the nitride semiconductor layer which doped the p type impurity is

carried out as technology, and the technology which produces a p type nitride semiconductor is known by removing hydrogen (patent No. 2540791). However, although the p type nitride semiconductor was obtained, the resistivity has more than number omega and cm. Then, crystallinity becomes good by making this p type layer into p type superlattice layers, according to our examination, this p layer resistivity [ single or more figures ] can be made low as compared with the former, and the effect that Vf makes it fall shows up notably.

[0031]In this Embodiment 1, the 1st layer (the 2nd layer) is preferably set to  $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0 \leq x \leq 1$ ) as mentioned above, Since the superlattice layers which do not have a good crystalline crack by constituting the 2nd layer (the 1st layer) from  $\text{Aluminum}_y\text{Ga}_{1-y}\text{N}$  ( $0 \leq y \leq 1, x \neq y = 0$ ) can be formed, an element life can be raised.

[0032]Next, we compare and explain the conventional example and this invention which were indicated by publicly known document containing the Patent Gazette for which it applied before. First, we proposed JP,H8-228048,A previously as technology similar to this invention. This technology is technology which forms the multilayer film which becomes the outside of the n type clad layer which sandwiches an active layer, and/or the outside (that is, side which is

separated from an active layer) of a p type clad layer from AlGa<sub>N</sub>, Ga<sub>N</sub>, InGa<sub>N</sub>, etc. as a light reflection film of a laser beam. Since a multilayer film is formed as a light reflection film, and the thickness of that each layer is designed by  $\lambda / 4n$  ( $n$ : the refractive index of a nitride semiconductor,  $\lambda$ :wavelength), this technology is dramatically thick. Therefore, each thickness of a multilayer film is not the thickness below an elastic strain limit. The laser device of the structure which inserted the active layer into USP No. 5,146,465 by the mirror which consists of aluminum<sub>x</sub>Ga<sub>1-x</sub>N/aluminum<sub>y</sub>Ga<sub>1-y</sub>N is indicated. In order to make AlGa<sub>N</sub>/AlGa<sub>N</sub> act as a mirror like [ this technology ] last technology, thickness of each layer must be thickened. It is dramatically difficult to laminate a many layers hard semiconductor still like AlGa<sub>N</sub> without a crack.

[0033]On the other hand, each thickness of the 2nd layer is set to the 1st constitute superlattice layers from this embodiment (both are preferably set to 100 Å or less and below critical thickness.), and it differs from said technology. The effect by the strained super lattice of the nitride semiconductor which constitutes superlattice layers from this invention is used, crystallinity is raised, and  $V_f$  is reduced.

[0034]The method of laminating AlN and GaN of a thin film to JP,5-110138,A

and JP,H5-110139,A, and obtaining the crystal of aluminum<sub>y</sub>Ga<sub>1-y</sub>N is indicated.

In order to obtain the mix crystal of aluminum<sub>y</sub>Ga<sub>1-y</sub>N of a predetermined mixed crystal ratio, this technology is technology which laminates AlN of tens of Å thickness, and GaN, and differs from the technology of this invention. And since it does not have an active layer which consists of InGaN(s), a crack goes into superlattice layers easily. The light emitting device of terrorism structure is indicated by JP,H6-21511,A and the No. 268257 [ six to ] gazette to the double which has an active layer of the multiple quantum well structure which laminated GaN, InGaN or InGaN, and InGaN. In this invention, it is the technology which makes layers other than an active layer multiple quantum well structure, and differs also from this technology.

[0035]Furthermore, with the element of this invention, when equipping an active layer with a nitride semiconductor like InGaN which contains indium at least, the effect of superlattice shows up notably. Bandgap energy is small and the InGaN active layer is most suitable as an active layer of a nitride semiconductor device. Therefore, since an active layer, a bandgap energy difference, and refractive index difference can be enlarged if the superlattice layers which consist of In<sub>x</sub>Ga<sub>1-x</sub>N and aluminum<sub>y</sub>Ga<sub>1-y</sub>N are formed as a layer which sandwiches an

active layer, When these superlattice layers realize a laser device, it operates as a dramatically outstanding optical confinement layer (it applies to the nitride semiconductor device of Embodiment 2). Since InGaN is [ the character of a crystal ] soft compared with the nitride semiconductor containing aluminum like other AlGaN(s), if InGaN is made an active layer, a crack will become furthermore difficult to go into each laminated whole nitride semiconductor layer. Conversely, when a nitride semiconductor like AlGaN is made into an active layer, since the character of the crystal is hard, it is in the tendency for a crack to go into the whole crystal easily.

[0036]It is desirable to adjust still more preferably 500 Å or less of thickness [ 300 Å or less of ] of p side contact layer to 200 Å or less most preferably furthermore. because, it mentioned above -- as -- resistivity -- several -- more than ohm-cm adjusts the thickness of a certain p type nitride semiconductor layer to 500 Å or less -- further -- resistivity -- it seems to be low -- since \*\*\*\*\* is made, the current in a threshold value and voltage fall. Quantity of the hydrogen removed from a p type layer can be increased, and resistivity can be reduced further.

[0037]As mentioned above, in the nitride semiconductor device of this



Embodiment 1, as explained in full detail, since the 1st layer and 2nd layer constitute the p type clad layer 5 from laminated superlattice layers, this p type clad layer 5 is extremely made to low resistance, and  $V_f$  of this element can be made low.

[0038]According to above Embodiment 1, although superlattice layers were used for the p side clad layer 5, this invention may use p type superlattice layers not only for this but for the p side contact layer 6. That is, the p side contact layer 6 into which current (electron hole) is poured can also be made into the p type superlattice layers by which the 1st layer that consists of  $\text{In}_x\text{Ga}_{1-x}\text{N}$ , and the 2nd layer that consists of  $\text{Aluminum}_y\text{Ga}_{1-y}\text{N}$  were laminated. When the p type contact layer 6 is made into superlattice layers and the bandgap energy of the 1st layer is smaller than the 2nd layer, It is preferred to consider it as the layer which bandgap energy makes the outermost surface the 1st layer that consists of small  $\text{In}_x\text{Ga}_{1-x}\text{N}$ , and contacts p electrode, contact resistance with p electrode becomes small, and desirable OMIKKU is obtained by this. This is because the direction of the 1st layer with small bandgap energy is in the tendency for the nitride semiconductor layer whose carrier concentration is higher than the 2nd layer to be easy to be obtained. When forming further an above-mentioned p

side clad layer and p type nitride semiconductor layers other than p side contact layer in a p type nitride semiconductor layer field, superlattice layers may constitute this p type nitride semiconductor layer from this invention.

[0039]According to above Embodiment 1, although superlattice layers were used for the p side clad layer 5, this invention may use n type superlattice layers for the n side contact layer 3 of not only a p type nitride semiconductor layer field but a n type nitride semiconductor field. Thus, when making the n side contact layer 3 into superlattice layers, n type impurities, such as Si and germanium, can be doped in the 1st layer and/or 2nd layer, and the superlattice layers which have a n type conductivity type can be formed as the n type contact layer 3 between the substrate 1 and the active layer 4, for example. In this case, it was checked that it is in the tendency for lateral resistance to fall if especially the n type contact layer 3 is made into the superlattice layers which differ in impurity concentration, and for threshold voltage and current to fall in LD.

[0040]This about the case where the superlattice layers which doped many n type impurities are formed in the direction of the big layer of bandgap energy as a contact layer by the side of a n layer. The effect in which the operation similar to the following HEMT(s) (High-Electron-Mobility-Transistor) appeared is

guessed. The 1st layer with a large band gap by which the n type impurity was doped (the 2nd layer), A band gap in the superlattice layers which laminated the 2nd layer (the 1st layer) of small undoping {(undope) the state where the impurity is not doped below as for; is called undoping}. By the heterojunction interface of the layer which added the n type impurity, and a undoped layer, the big layer side of bandgap energy depletion-izes, and an electron (two dimensional electron gas) is accumulated in the interface before and behind the thickness (100 Å) by the side of the small layer of bandgap energy. In order not to receive dispersion by an impurity when an electron runs since this two dimensional electron gas turns on the small layer side of bandgap energy, the degree of electron transfer of superlattice layers becomes high, and is guessed that resistivity falls.

[0041]In this invention, when providing the cladding layer by the side of n in a n type nitride semiconductor layer field, it is good also considering the cladding layer by the side of this n as superlattice layers. When forming n type nitride semiconductor layers other than n side contact layer and a n side clad layer in a n type nitride semiconductor layer field, it is good also considering this n type nitride semiconductor layer as superlattice layers. However, when providing the

nitride semiconductor layer which consists of superlattice layers in a n type nitride semiconductor layer field, it cannot be overemphasized that it is desirable to make into a superstructure the n side clad layer as a carrier confining layer or the n side contact layer 3 into which current (electron) is poured.

[0042]thus, when looking superlattice layers like [ the n type nitride semiconductor layer field between the active layer 4 and the substrate 1 ] and providing them, it is not necessary to dope an impurity in the 1st layer and the 2nd layer which constitute superlattice layers It is because there is character which becomes a n type even when a nitride semiconductor is undoped.

However, it is more desirable to dope n type impurities, such as Si and germanium, in the 1st layer and the 2nd layer, and to establish the difference of impurity concentration as mentioned above, when forming in the n layer side.

[0043]As mentioned above, crystalline improvement is mentioned like the case where the effect at the time of forming superlattice layers in a n type nitride semiconductor layer field provides superlattice layers in a p type nitride semiconductor layer field. When it explains in detail, in the case of the nitride semiconductor device which has a hetero-junction, the carrier confining layer of a n type and a p type usually comprises AlGa<sub>N</sub> with larger bandgap energy than

an active layer. Crystal growth is dramatically difficult for AlGaIn, for example, when you are going to make it grow up by thickness of 0.5 micrometers or more with single composition, there is character in which a crack enters easily during a crystal. However, since a good crystalline thing will be obtained only in the 1st single layer and the 2nd layer if the 1st layer and the 2nd layer are laminated by the thickness below an elastic strain limit like this invention and it is superlattice layers, while crystallinity has been good also as thick superlattice layers of thickness, a cladding layer can grow the whole. Therefore, since the crystallinity of the whole nitride semiconductor becomes good and the mobility of a n type region becomes large,  $V_f$  falls with the element which made the superlattice layers the cladding layer. It seems that an effect similar to the above mentioned HEMT comes to show up notably when the impurity of Si and germanium is doped to superlattice layers and superlattice layers are made into a contact layer, and threshold voltage and  $V_f$  can be reduced further.

[0044] Thus, the cladding layer as a carrier confining layer formed in the n type region or p type region where superlattice layers sandwich an active layer in this invention, Since it is used as the light guide layer of an active layer, or a current injection layer formed by an electrode touching, it is desirable to adjust so that

the average bandgap energy of the nitride semiconductor which constitutes superlattice layers may become larger than an active layer.

[0045]Embodiment 2 concerning embodiment 2., next this invention is described.

Drawing 2 is the structure of the nitride semiconductor device of Embodiment 2 concerning this invention a shown typical sectional view (section vertical to the resonant direction of a laser beam), and this nitride semiconductor device, For example, on the substrates 10, such as sapphire which makes C side a principal surface, A n type nitride semiconductor layer field. (it consists of the n side contact layer 12, the crack prevention layer 13, the n side clad layer 14, and the n side light guide layer 15.) -- by a p type nitride semiconductor field (it consists of the cap layer 17, the p side light guide layer 18, the p side clad layer 19, and the p side contact layer 20.). It is the nitride semiconductor laser diode element provided with the active layer 16 which consists of a sandwiched nitride semiconductor.

[0046]Here the nitride semiconductor device of this Embodiment 2, The threshold voltage of the nitride semiconductor device which is an LD element is low set up by forming the n side clad layer 14 in a n type nitride semiconductor layer field by superlattice layers, and forming the p side clad layer 19 in a p type

nitride semiconductor field by superlattice layers. The nitride semiconductor device of Embodiment 2 which starts this invention with reference to this drawing 2 below is explained in detail.

[0047]In the nitride semiconductor device of this Embodiment 2, First, the n side contact layer 12 is formed via the buffer layer 11 and the 2nd buffer layer 112 on the substrate 10, further, on the n side contact layer 12, the crack prevention layer 13, the n side clad layer 14, and the n side light guide layer 15 are laminated, and a n type nitride semiconductor layer field is formed. The n lateral electrode 23 which carries out ohmic contact to the n side contact layer 12 is formed in the surface of the n side contact layer 12 exposed to the both sides of the crack prevention layer 13, respectively, and the n side pad electrode for wire bonding is formed on these n lateral electrodes 23, for example. And the active layer 16 which consists of nitride semiconductors is formed on the n side light guide layer 15, further, on this active layer 16, the cap layer 17, the p side light guide layer 18, the p side clad layer 19, and the p side contact layer 20 are laminated, and a p type nitride semiconductor layer field is formed. The p lateral electrode 21 which carries out ohmic contact to these p side contact layers 20 is formed on the p side contact layer 20, and p side pad electrode for wire bonding

is formed on these p lateral electrodes 21, for example. By the upper part of the p side contact layer 20 and the p side clad layer 19. By the ridge part of the shape of Mine extended for a long time being constituted by the resonant direction, and forming this ridge part in it, In the active layer 16, light is shut up crosswise (direction which intersects perpendicularly with a resonant direction), and laser oscillation of the resonator which resonates to the longitudinal direction of a ridge part is produced and carried out using the cleavage plane by which cleavage was carried out in the direction vertical to a ridge part (electrode of stripe shape).

[0048]Next, each component of the nitride semiconductor device of Embodiment 2 is explained.

(Substrate 10) R side besides the sapphire which makes C side the substrate 10 with a principal surface, Semiconductor substrates, such as SiC (6H, 4H, and 3C are included), ZnS, ZnO, GaAs, GaN, etc. besides the sapphire which makes A side a principal surface, and other insulating substrates like a spinel ( $\text{MgAl}_2\text{O}_4$ ), can be used.

[0049](Buffer layer 11) The buffer layer 11 grows up AlN, GaN, AlGaIn, InGaIn, etc. at the temperature of 900 °C or less, for example, and is formed in a



thickness number (10 Å - hundreds of Å). In order that this buffer layer 11 may ease the grating constant injustice of a substrate and a nitride semiconductor, it forms, but it is also possible to omit according to the growing method of a nitride semiconductor, the kind of substrate, etc.

[0050](The 2nd buffer layer 112) On said buffer layer 11, the 2nd buffer layer 112 is a layer which consists of a nitride semiconductor of the single crystal grown up at the elevated temperature rather than said buffer layer, and has a thick film rather than the buffer layer 11. the nitride semiconductor layer which this 2nd buffer layer 112 considers it as a layer with less n type impurity concentration than the n side contact layer 12 grown up into the next, or does not dope a n type impurity -- if it is a GaN layer preferably, the crystallinity of the 2nd buffer layer 112 will become good. If a n type impurity is most preferably set to undoped GaN, a nitride semiconductor with the most sufficient crystallinity will be obtained. If not less than several micrometers thickness tends to constitute n side contact layer which forms the negative electrode like before from the single nitride semiconductor layer of high carrier concentration, it is necessary to grow up a layer with large n type impurity concentration. As for the layer of a thick film with large impurity concentration, crystallinity tends to worsen. For this reason,

on a bad crystalline layer, even if it grows up other nitride semiconductors, such as an active layer, other layers will succeed a crystal defect and crystalline improvement cannot be expected. Then, before growing up 12 layers of n side contact layers, carrier concentration can grow up the good large crystalline n side contact layer 12 by growing up the 2nd good crystalline buffer layer 112 with small impurity concentration. As for the thickness of this 2nd buffer layer 112, it is still more preferably desirable most preferably to adjust to 1 micrometers or more and 20 micrometers or less 0.5 micrometers or more 0.1 micrometers or more. When the 2nd buffer layer 112 is thinner than 0.1 micrometer, the n type contact layer 12 with large impurity concentration must be grown up thickly, and it is in the tendency which can seldom expect crystalline improvement in the n side contact layer 12. When thicker than 20 micrometers, it is in the tendency for a crystal defect to increase easily in the 2nd buffer layer 112 the very thing. It is considered as the advantage into which the 2nd buffer layer 112 is grown up thickly, and improvement in heat dissipation nature is mentioned. That is, when a laser device is produced, the life of a laser device improves that heat spreads easily in the 2nd buffer layer 112. Furthermore, the light leaking of a laser beam spreads within the 2nd buffer layer 112, and it becomes easy to obtain the laser

beam near an ellipse form. The 2nd buffer layer 112 may be omitted when conductive substrates, such as GaN, SiC, and ZnO, are used for a substrate.

[0051](n side contact layer 12) The n side contact layer 12 is a layer which acts as a contact layer which forms the negative electrode, and it is desirable to adjust to 0.2 micrometers or more and 4 micrometers or less. If thinner than 0.2, when forming the negative electrode later, it is difficult to control an etching rate so that this layer may be exposed, and when not less than 4 micrometers is used, on the other hand, it is in the tendency for crystallinity to worsen under the influence of an impurity. The range of the n type impurity doped to the nitride semiconductor of this n side contact layer 12 The range of  $1 \times 10^{17}/\text{cm}^3$  -  $1 \times 10^{21}/\text{cm}^3$ , It is desirable to adjust to  $1 \times 10^{18}/\text{cm}^3$  -  $1 \times 10^{19}/\text{cm}^3$  still more preferably.

Since the material of n electrode and desirable OMIKKU will become is hard to be obtained if smaller than  $1 \times 10^{17}/\text{cm}^3$ , In a laser device, a fall of a threshold current and voltage cannot be expected, but since the leakage current of the element itself will increase and crystallinity will also worsen if larger than  $1 \times 10^{21}/\text{cm}^3$ , it is in the tendency for the life of an element to become short. In the n side contact layer 12, in order to make small ohmic contact resistance with the n electrode 23, it is desirable to make larger than the n cladding layer 14

concentration of the impurity which raises the carrier concentration of these n side contact layers 12. The n side contact layer 12 acts not as a contact layer but as a buffer layer, when providing the negative electrode in a substrate at the substrate rear side using conductive substrates, such as GaN, SiC, and ZnO.

[0052]At least one layer of the 2nd buffer layer 11 and the n side contact layers 12 can also be made into superlattice layers. If it is superlattice layers, the crystallinity of this layer will become good by leaps and bounds, and a threshold current will fall. Let the desirable n side contact layer 12 in which thickness is thinner than the 2nd buffer layer 11 be superlattice layers. In the case where the n side contact layer 12 is made into the superstructure which comes to laminate the 1st layer that differs in bandgap energy mutually, and the 2nd layer, By exposing the desirable small layer of bandgap energy and forming the n electrode 23, contact resistance with the n electrode 23 can be made low, and can reduce a threshold value. As a n type nitride semiconductor and a material of the n electrode 23 in which desirable OMIKKU is obtained, metal or alloys, such as aluminum, Ti, W, Si, Zn, Sn, and In, are mentioned.

[0053]By making the n type contact layer 12 into the superlattice layers which differ in impurity concentration, lateral resistance can be made low by an effect

similar to HEMT explained in Embodiment 1, and the threshold voltage of an LD element and current can be made low.

[0054](Crack prevention layer 13) The crack prevention layer 13 consists of  $\text{In}_{0.1}\text{Ga}_{0.9}\text{N}$  which  $\text{cm}^{-3}$  [ $5 \times 10^{18}$ ]-doped Si, for example, and has 500-Å thickness, for example. This crack prevention layer 13 can prevent a crack from entering into the nitride semiconductor layer containing aluminum formed on it the n type nitride semiconductor containing In and by growing up InGaN preferably and forming. As for this crack prevention layer 13, it is preferred to make it grow up by 100 Å or more and 0.5 micrometer or less of thickness. If thinner than 100 Å, it will be hard to act as crack prevention as mentioned above, and when thicker than 0.5 micrometer, it is in the tendency for the crystal itself to be discolored in black. This crack prevention layer 13 may be omitted, when using the n side contact layer 12 as superlattice like this Embodiment 1, or when making into superlattice layers the n side clad layer 14 grown up into the next.

[0055](N side clad layer 14 which consists of n type superlattice) A n side clad layer, For example, it consists of n type  $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$  which  $\text{cm}^{-3}$  [ $5 \times 10^{18}$ ]-doped Si, The 1st layer that has 20-Å thickness, and the 2nd layer that consists of undoped GaN and has 20-Å thickness consist of superlattice layers

laminated by turns, and it has 0.5 micrometer of thickness on the whole. This n type clad layer 14 acts as a carrier confining layer and an optical confinement layer, The nitride semiconductor which contains aluminum for one of layers when it is considered as superlattice layers, It is desirable to grow up AlGaIn preferably and 2 micrometers or less of 100 Å or more can grow a good carrier confining layer by making it grow up at 500 Å or more and 1 micrometer or less still more preferably. Although this n type clad layer 14 can also be grown up with a single nitride semiconductor, the good crystalline carrier confining layer where a crack does not have considering it as superlattice layers can be formed.

[0056](n side light guide layer 15) The n side light guide layer 15 consists of n type GaN which  $\text{cm}^{-3}$   $[5 \times 10^{18}]$ -doped Si, for example, and has 0.1 micrometer of thickness. As for this n side light guide layer 6, it is desirable to act as a light guide layer of an active layer, to grow up GaN and InGaIn, and to form, and it is usually desirable to make it grow up by 200 Å - 1 micrometer of thickness still more preferably 100 Å - 5 micrometers. This light guide layer 15 can also be made into superlattice layers. When making the n side light guide layer 15 and the n side clad layer 14 into superlattice layers, average bandgap energy of the nitride semiconductor layer which constitutes superlattice layers is made larger

than an active layer. When considering it as superlattice layers, a n type impurity may be doped in either [ at least ] the 1st layer or the 2nd layer, and undoping may be sufficient. The superlattice by which a undoped nitride semiconductor independent or a undoped nitride semiconductor was laminated may be sufficient as this light guide layer 15.

[0057](Active layer 16) The well layer which the active layer 16 consists of  $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$  which doped Si by  $8 \times 10^{18}/\text{cm}^3$ , for example, and has 25-A thickness, It consists of  $\text{In}_{0.051}\text{Ga}_{0.95}\text{N}$  which  $\text{cm}^{-3}$  [  $8 \times 10^{18}$  ]-doped Si, and constitutes from multiple quantum well structure (MQW) which has predetermined thickness by laminating by turns the barrier layer which has 50-A thickness. In the active layer 16, an impurity may be doped to both a well layer and a barrier layer, and it may dope to either. When a n type impurity is doped, it is in the tendency for a threshold value to fall. Superlattice layers are distinguished in order to certainly laminate the small well layer of bandgap energy, and the barrier layer in which bandgap energy is smaller than a well layer, in making the active layer 16 into multiple quantum well structure in this way. 100 A or less of thickness [ 70 A or less of ] of a well layer shall be 50 A or less most preferably. 150 A or less of thickness [ 100 A or less of ] of a barrier layer shall be 70 A or less most

preferably.

[0058](p side cap layer 17) Rather than the active layer 16, bandgap energy is large, for example, consists of p type aluminum<sub>0.3</sub>Ga<sub>0.7</sub>N which cm<sup>-3</sup>[ 1x10<sup>20</sup>]-doped Mg, and the p side cap layer 17 has 200-A thickness, for example.

Although it is preferred in this Embodiment 2 to use the cap layer 17 in this way, since this cap layer is formed in thin thickness, it is good also as an i type which doped the n type impurity and with which the carrier was compensated by this invention. 0.1 micrometer or less of thickness [ 500 A or less of ] of the p side cap layer 17 is most preferably adjusted to 300 A or less still more preferably. It is because a crack enters easily into the p side cap layer 17 and a good crystalline nitride semiconductor layer cannot grow easily, if it is made to grow up by thickness thicker than 0.1 micrometer. It is because it becomes impossible to pass the p type capping layer 17 from which a carrier becomes that the thickness of the p side cap layer 17 is 0.1 micrometers or more with this energy barrier according to the tunnel effect, When passage of the carrier by this tunnel effect is taken into consideration, it is preferred to set it as 500 A or less and 300 more A or less to have mentioned above.

[0059]To the p side cap layer 17, in order to make an LD element easy to



oscillate, it is preferred that the composition ratio of aluminum uses and forms large AlGa<sub>N</sub>, and it becomes easy to oscillate an LD element, so that this AlGa<sub>N</sub> is formed thinly. For example, if Y value is 0.2 or more aluminum<sub>Y</sub>Ga<sub>1-Y</sub>N, adjusting to 500 Å or less is desirable. Although the minimum in particular of the thickness of the p side cap layer 17 does not limit, it is desirable to form by thickness of 10 Å or more.

[0060](p side light guide layer 18) Bandgap energy is smaller than the p side cap layer 17, for example, consists of p type GaN which cm<sup>-3</sup>[ 1x10<sup>20</sup>]-doped Mg, and the p side light guide layer 18 has 0.1 micrometer of thickness. As for this p side light guide layer 18, it is desirable to act as a light guide layer of the active layer 16, to make it grow up by GaN and InGa<sub>N</sub> as well as the n side light guide layer 15, and to form. This layer acts as a desirable light guide layer by acting also as a buffer layer at the time of growing up the p side clad layer 19, and growing up 100 Å - 5 micrometers by 200 Å - 1 micrometer of thickness still more preferably. Although this p side light guide layer usually dopes p type impurities, such as Mg, and considers it as a p type conductivity type, it is not necessary to dope an impurity in particular. This p side light guide layer can also be made into superlattice layers. When considering it as superlattice layers, a p type impurity

may be doped in either [ at least ] the 1st layer or the 2nd layer, and undoping may be sufficient.

[0061](P side clad layer 19= superlattice layers) The p side clad layer 19, For example, the 1st layer that consists of p type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N which cm<sup>-3</sup>[ 1x10<sup>20</sup>]-doped Mg, and has 20-A thickness, for example, For example, it consists of p type GaN which cm<sup>-3</sup>[ 1x10<sup>20</sup>]-doped Mg, and the 2nd layer that has 20-A thickness consists of superlattice layers laminated by turns. This p side clad layer 19 acts as a carrier confining layer as well as the n side clad layer 14, and acts as a layer for reducing especially resistivity of a p type layer. Although thickness in particular of this p side clad layer 19 is not limited, either, it is desirable to form at 500 A or more and 1 micrometer or less still more preferably 2 micrometers or less 100 A or more.

[0062](p side contact layer 20) On the p side clad layer 19, the p side contact layer 20 consists of p type GaN which cm<sup>-3</sup>[ 2x10<sup>20</sup>]-doped Mg, for example, and has 150-A thickness, for example. This p side contact layer 20 can be constituted from p type In<sub>x</sub>Al<sub>y</sub>Ga<sub>1-x-y</sub>N (0≤X, 0≤Y, X+Y≤1), and if referred to as GaN which doped Mg as mentioned above preferably, the p electrode 21 and the most desirable ohmic contact will be obtained. It is desirable to adjust still

more preferably 500 Å or less of thickness [ 300 Å or less of ] of p side contact layer to 200 Å or less most preferably furthermore. because, it mentioned above -- as -- resistivity -- several -- more than ohm-cm adjusts thickness of a certain p type nitride semiconductor layer to 500 Å or less -- further -- resistivity -- it seems to be low -- since \*\*\*\*\* is made, current in a threshold value and voltage fall.

Quantity of hydrogen removed from a p type layer can be increased, and resistivity can be reduced further.

[0063]The p side contact layer 20 can also be made into superlattice layers in this invention. Especially in considering it as superlattice layers, it laminates the 1st layer and 2nd layer that differ in bandgap energy, the -- the [ 1+ ] -- the [ 2+ ] -- 1+ the 2+ ... as -- if it laminates and is finally made exposed [ a layer with smaller bandgap energy ], the p electrode 21 and desirable ohmic contact will be obtained. As a material of the p electrode 21, nickel, Pd, nickel/Au, etc. can be mentioned, for example.

[0064]The insulator layer 25 which consists of SiO<sub>2</sub> is formed in the surface of a nitride semiconductor layer exposed between the p electrode 21 and the n electrode 23 in this Embodiment 2 as shown in drawing 2, The p pad electrode 22 electrically connected with the p electrode 21 via an opening formed in this

insulator layer 25 and the n pad electrode 24 connected with the n electrode 23 are formed. this p pad electrode 22 extends surface area of the substantial p electrode 21 -- the p electrode side -- wire bonding -- being able to be made to carry out die bonding, on the other hand, the n pad electrode 24 prevents peeling of the n electrode 23.

[0065]The nitride semiconductor device of above Embodiment 2 is provided with the good crystalline p type clad layer 19 which is the superlattice layers which made the 1st layer and the 2nd layer the thickness below an elastic strain limit, and were laminated. By this, since the nitride semiconductor device of this Embodiment 2 can make low the single or more figures resistance of the p side clad layer 19 as compared with the p side clad layer which does not have a superstructure, it can make threshold voltage and current low.

[0066]The p side clad layer 19 which contains p type aluminum $\gamma$ Ga $_{1-\gamma}$ N in the nitride semiconductor device of this Embodiment 2 is touched, By forming the thickness thinly with 500 Å or less by making the small nitride semiconductor of bandgap energy into the p side contact layer 20, The carrier concentration of the p side contact layer 20 becomes high substantially, p electrode and desirable OMIKKU are obtained, and the threshold current of an element and voltage can

be made low. Since it has the 2nd buffer layer 112 before growing up n side contact layer, the crystallinity of the nitride semiconductor layer grown up on the 2nd buffer layer 112 becomes good, and a long lasting element can be realized. If n side contact layer grown up on the 2nd buffer layer 112 is preferably used as superlattice, lateral resistance becomes low and the low element of threshold voltage and a threshold current can be realized.

[0067]In equipping the active layer 16 with a nitride semiconductor like InGaN which contains indium at least in the LD element of this Embodiment 2, It is preferred that  $\text{In}_x\text{Ga}_{1-x}\text{N}$  and aluminum $_y\text{Ga}_{1-y}\text{N}$  use the superlattice layers laminated by turns as a layer (the n side clad layer 14 and the p side clad layer 19) which sandwiches the active layer 16. By this, since the bandgap energy difference of the active layer 16 and these superlattice layers and refractive index difference can be enlarged, these superlattice layers can be operated as a dramatically outstanding optical confinement layer, when realizing a laser device. Since InGaN is [ the character of a crystal ] soft compared with the nitride semiconductor containing aluminum like other AlGaN(s), if InGaN is made an active layer, a crack will become furthermore difficult to go into each laminated whole nitride semiconductor layer. The life of an LD element can be lengthened

by this.

[0068]In the case of the semiconductor device of the double hetero structure of having the active layer 16 which has quantum well structure like this

Embodiment 2, the active layer 16 is touched, The p side cap layer 17 which consists of a nitride semiconductor of 0.1 micrometer or less of thickness with larger bandgap energy than the active layer 16, and the p side cap layer 17 which consists of a nitride semiconductor which contains aluminum preferably are formed, The p side light guide layer 18 in which bandgap energy is smaller than the p side cap layer 17 is formed in the position which is separated from an active layer rather than the p side cap layer 17, It is dramatically more preferred than the p side light guide layer 18 to form the p side clad layer 19 which has a superstructure which contains a nitride semiconductor with a larger band gap than the p side light guide layer 18 and the nitride semiconductor which contains aluminum preferably in the position which is separated from an active layer. And in order that the electron poured in from the n layer since bandgap energy of the p side cap layer 17 was enlarged may be prevented by this p side cap layer 17, and may be shut up and an electron may not overflow an active layer, the leakage current of an element decreases.

[0069]Although the nitride semiconductor device of above Embodiment 2 showed a structure desirable as a structure of a laser device, What is necessary is just to have at least one layer of n type superlattice layers from the active layer 16 in this invention to the lower n type nitride semiconductor layer field (n type layer side), What is necessary is just to also have at least one layer of p type superlattice layers from the active layer 16 to the upper p type nitride semiconductor layer field (p type layer side), and element composition in particular is not specified. However, said superlattice layers are formed in the p side clad layer 19 as a carrier confining layer when forming in the p layer side, When forming in the n layer side and forming as the n contact layer 12 as a current injection layer which the n electrode 23 touched, or the n cladding layer 14 as carrier \*\*\*\*\* reduces  $V_f$  of an element, and a threshold value, it is in the most desirable tendency. It cannot be overemphasized that the same composition as the element of Embodiment 2 is applicable to a LED element (however, in a LED element, a ridge part is unnecessary).

[0070]In the nitride semiconductor device of Embodiment 2 constituted as mentioned above. In the atmosphere which does not contain H, for example, a nitrogen atmosphere, after each layer is formed, It is preferred to perform

annealing, for example at 700 °C not less than 400 °C, and since each layer of a p type nitride semiconductor layer field can be further low-resistance-ized by this, threshold voltage can be further made low by this.

[0071]In the nitride semiconductor device of Embodiment 2, the p electrode 21 which becomes the surface of the p side contact layer 12 from nickel and Au was formed in stripe shape, n side contact layer was symmetrically exposed to this p electrode 21, and the n electrode 23 is formed all over almost [ of that n side contact layer surface ]. Thus, when the structure of forming the n electrode 23 symmetrically with the both sides of the p electrode 21 when an insulating substrate is used makes threshold voltage low, it is dramatically advantageous.

[0072]In this Embodiment 2, the dielectric multilayer which consists of SiO<sub>2</sub> and TiO<sub>2</sub> may be formed in the cleavage plane (resonator face) which carried out cleavage in the direction vertical to a ridge part (electrode of stripe shape).

[0073]Thus, the cladding layer as a carrier confining layer formed in the n type region or p type region where superlattice layers sandwich an active layer in this invention, Since it is used as the light guide layer of an active layer, or a current injection layer formed by an electrode touching, it is desirable to adjust so that



the average bandgap energy of the nitride semiconductor which constitutes superlattice layers may become larger than an active layer.

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## EXAMPLE

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[Working example] Hereafter, in working example, this invention is explained in full detail.

[Working example 1] Working example 1 concerning this invention is an example of creation of the nitride semiconductor device (LD element) shown in drawing 2, and is produced in the following procedures. First, passing hydrogen, after setting the substrate 10 which consists of sapphire (C side) in a reaction vessel and replacing the inside of a container enough from hydrogen, the temperature of a substrate is raised to 1050 °C and a substrate is cleaned. Then, temperature is lowered to 510 °C, hydrogen is used for carrier gas, ammonia (NH<sub>3</sub>) and TMG (trimethylgallium) are used for material gas, and the 1st buffer layer 11 that comes from GaN on the substrate 10 is grown up by about 200-Å thickness.

[0075] Only TMG is stopped after buffer layer 11 growth, and temperature is raised to 1050 °C. If it becomes 1050 °C, similarly TMG and ammonia gas will be used for material gas, and the 2nd buffer layer 112 that consists of the undoping

GaN of carrier concentration  $1 \times 10^{18} / \text{cm}^3$  will be grown up by 5-micrometer thickness. the 2nd buffer layer --  $\text{In}_x\text{Al}_y\text{Ga}_{1-x-y}\text{N}$  ( $0 \leq x$ .) Although it can constitute from  $0 \leq y$  and  $x+y \leq 1$  and the presentation in particular is not asked, it is preferably undoped and aluminum (Y value) sets to 0.1 or less aluminum $_y\text{Ga}_{1-y}\text{N}$  and most desirable undoped GaN. Then, silane gas ( $\text{SiH}_4$ ) is used for TMG, ammonia, and impurity gas at  $1050^\circ\text{C}$ , and the n side contact layer 12 which consists of n type GaN which  $\text{cm}^{-3}$  [ $1 \times 10^{19}$ ]-doped Si is grown up by 1 micrometer of thickness. When this n side contact layer 12 is formed by superlattice, it is still more preferred.

[0076] Temperature shall be  $800^\circ\text{C}$  and to material gas Next, TMG, TMI (trimethylindium), Silane gas is used for ammonia and impurity gas, and the crack prevention layer 13 which consists of  $\text{In}_{0.1}\text{Ga}_{0.9}\text{N}$  which  $\text{cm}^{-3}$  [ $5 \times 10^{18}$ ]-doped Si is grown up by 500-A thickness. And temperature shall be  $1050^\circ\text{C}$  and TMA, TMG, ammonia, and silane gas are used, The 1st layer that consists of n type aluminum $_{0.2}\text{Ga}_{0.8}\text{N}$  which  $\text{cm}^{-3}$  [ $5 \times 10^{18}$ ]-doped Si is grown up by 20-A thickness, then TMA and Silane are stopped and the 2nd layer that consists of the undoping GaN is grown up by 20-A thickness. And this operation is repeated 100 times, respectively and the n side clad layer 14 which consists of

superlattice layers of 0.4 micrometer of the total thickness is grown up.

[0077]Then, the n side light guide layer 15 which consists of n type GaN which  $\text{cm}^{-3}$   $[5 \times 10^{18}]$ -doped Si at 1050 \*\* is grown up by 0.1 micrometer of thickness.

Next, the active layer 16 is grown up using TMG, TMI, ammonia, and Silang. The active layer 16 holds temperature at 800 \*\*, and grows up the well layer which consists of  $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$  which doped Si by  $8 \times 10^{18}/\text{cm}^3$  first by 25-A thickness.

Next, the barrier layer which consists of  $\text{In}_{0.01}\text{Ga}_{0.99}\text{N}$  which  $\text{cm}^{-3}$   $[8 \times 10^{18}]$ -doped Si at the same temperature only by changing the mole ratio of TMI is grown up by 50-A thickness. This operation is repeated twice and the active layer 16 of the multiple quantum well structure (MQW) of 175 A of the total thickness that finally laminated the well layer is grown up.

[0078]Raise temperature to 1050 \*\* and to material gas Next, TMG, TMA, ammonia,  $\text{Cp}_2\text{Mg}$  (magnesium cyclopentadienyl) is used for impurity gas, The p side cap layer 17 which consists of p type aluminum $_{0.3}\text{Ga}_{0.7}\text{N}$  in which bandgap energy was large and  $\text{cm}^{-3}$   $[1 \times 10^{20}]$ -doped Mg rather than the active layer is grown up by 300-A thickness. Then, the p side light guide layer 18 which bandgap energy becomes at 1050 \*\* from p type GaN smaller than the p side cap layer 17 to which Mg was  $\text{cm}^{-3}$   $[1 \times 10^{20}]$ -doped is grown up by 0.1

micrometer of thickness.

[0079]Then, TMA, TMG, ammonia, and  $\text{Cp}_2\text{Mg}$  are used, The 1st layer that consists of p type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N which  $\text{cm}^{-3}$  [  $1 \times 10^{20}$  ]-doped Mg at 1050 \*\* is grown up by 20-A thickness, Then, only TMA is stopped and the 2nd layer that consists of p type GaN which  $\text{cm}^{-3}$  [  $1 \times 10^{20}$  ]-doped Mg is grown up by 20-A thickness. And this operation is repeated 100 times, respectively and the p side clad layer 19 which consists of superlattice layers of 0.4 micrometer of the total thickness is formed. The p side contact layer 20 which finally consists of p type GaN which  $\text{cm}^{-3}$  [  $2 \times 10^{20}$  ]-doped Mg on the p side clad layer 19 at 1050 \*\* is grown up by 150-A thickness.

[0080]Temperature is lowered to a room temperature after ending reaction, among a nitrogen atmosphere, in a reaction vessel for a wafer, annealing is performed at 700 \*\* and a p type layer is low-resistance-ized further. As a wafer is picked out from a reaction vessel after annealing and it is shown in drawing 2, the p side contact layer 20 of the top layer and the p side clad layer 19 are etched with an RIE system, and it is considered as the ridge shape which has the stripe width of 4 micrometers.

[0081]Next, as a mask is formed in the ridge surface and it is shown in drawing 2,

it is made symmetrical to the ridge of stripe shape, and the surface of the n side contact layer 12 is exposed. Next, the p electrode 21 which consists of nickel and Au all over almost [ of the stripe ridge outermost surface of the p side contact layer 20 ] is formed. On the other hand, the n electrode 23 which consists of Ti and aluminum is formed all over almost [ of the n side contact layer 3 of stripe shape ].

[0082]Next, as shown in drawing 2, the insulator layer 25 which consists of SiO<sub>2</sub> is formed in the surface of a nitride semiconductor layer exposed between the p electrode 21 and the n electrode 23, and the p pad electrode 22 electrically connected with the p electrode 21 via this insulator layer 25 and the n pad electrode 24 are formed. A wafer which formed n electrode and p electrode as mentioned above shall be transported to polish equipment, the silicon on sapphire 1 of a side which does not form a nitride semiconductor shall be wrapped using a diamond polishing agent, and thickness of a substrate shall be 50 micrometers. After wrapping, 1 micrometer is polished with still finer abrasive soap, and a substrate face is made into mirror finished surface form.

[0083]The scribe after substrate polish and of the polished surface side is carried out, cleavage is carried out to bar shape in a direction vertical to an electrode of

stripe shape, and a resonator is produced to a cleavage plane. A dielectric multilayer which consists of  $\text{SiO}_2$  and  $\text{TiO}_2$  was formed in a resonator face, and finally, in a direction parallel to p electrode, Bar was cut and it was considered as a laser chip. Next, in [ when a chip was installed in a heat sink by face up (state which a substrate and a heat sink countered), wire bonding of each electrode was carried out and laser oscillation was tried at a room temperature ] a room temperature, With threshold current density  $2.9 \text{ kA/cm}^2$  and the threshold voltage  $4.4\text{V}$ , continuous oscillation with an oscillation wavelength of  $405 \text{ nm}$  was checked, and a life of 50 hours or more was shown.

[0084](Comparative example 1) n type GaN which did not grow up the 2nd buffer layer 112 and  $\text{cm}^{-3}$   $[1 \times 10^{19}]$ -doped Si for the n side contact layer 12 further on the other hand -- it being single, and 5 micrometers being grown up, and, 0.4 micrometer of n side clad layers 14 are grown up by a n type aluminum $_{0.2}\text{Ga}_{0.8}\text{N}$  single which  $\text{cm}^{-3}$   $[1 \times 10^{19}]$ -doped Si, 0.4 micrometer of p side clad layers 19 are grown up by a p type aluminum $_{0.2}\text{Ga}_{0.8}\text{N}$  single which  $1 \times 10^{20}$ - $\text{cm}^{-3}$ -doped Mg, 0.2 micrometer of single p type GaN(s) which furthermore  $\text{cm}^{-3}$   $[2 \times 10^{20}]$ -doped Mg for the p side contact layer 20 were grown up, and also a laser device was obtained like working example 1. That is, as basic constitution, as shown in

Table 1, it constitutes.

[0085]

[Table 1]

基板	10・・・サファイア	
バッファ層	11・・・GaN	200Å
nコンタクト層	12・・・Siドープn型Ga <sub>0.9</sub> N Si: $1 \times 10^{19} / \text{cm}^3$	5 $\mu\text{m}$
クラック防止層	13・・・Siドープn型Al <sub>0.1</sub> Ga <sub>0.9</sub> N Si: $5 \times 10^{18} / \text{cm}^3$	500Å
nクラッド層	14・・・Siドープn型Al <sub>0.2</sub> Ga <sub>0.8</sub> N Si: $5 \times 10^{18} / \text{cm}^3$	0.5 $\mu\text{m}$
n光ガイド層	15・・・Siドープn型Ga <sub>0.95</sub> N Si: $5 \times 10^{18} / \text{cm}^3$	0.1 $\mu\text{m}$
活性層 (MQW) (総膜厚175Å)	16・・・SiドープIn <sub>0.2</sub> Ga <sub>0.8</sub> N	25Å
	SiドープIn <sub>0.01</sub> Ga <sub>0.95</sub> N	50Å
	Si: $8 \times 10^{18} / \text{cm}^3$	
キャップ層	17・・・Mgドープp型Al <sub>0.1</sub> Ga <sub>0.9</sub> N Mg: $1 \times 10^{20} / \text{cm}^3$	300Å
p光ガイド層	18・・・Mgドープp型Ga <sub>0.95</sub> N Mg: $1 \times 10^{20} / \text{cm}^3$	0.1 $\mu\text{m}$
pクラッド層	19・・・Mgドープp型Al <sub>0.2</sub> Ga <sub>0.8</sub> N Mg: $1 \times 10^{20} / \text{cm}^3$	0.5 $\mu\text{m}$
pコンタクト層	20・・・Mgドープp型Ga <sub>0.95</sub> N Mg: $2 \times 10^{20} / \text{cm}^3$	0.2 $\mu\text{m}$

[0086]Although continuous oscillation was checked by threshold current density

7 kA/cm<sup>2</sup> as for a laser device of a comparative example constituted in this way,

threshold voltage has gone out in those or more [ 8.0 ] with V, and several

minutes.

[0087][Working example 2] The 1st layer that consists the n side contact layer 12

of n type aluminum<sub>0.05</sub>Ga<sub>0.95</sub>N which cm<sup>-3</sup>[ 2x10<sup>19</sup>]/-doped Si in working example

1 is grown up by 30-A thickness, Then, the 2nd layer that consists of undoped GaN is grown up by 30-A thickness, this is repeated, and it is considered as the superstructure of 1.2 micrometers of the total thickness. When it was considered as the laser device which has the same structure as working example 1, it is threshold current density 2.7 kA/cm<sup>2</sup> and the threshold voltage 4.2V, and, as for the other structure, the life also showed 60 hours or more.

[0088][Working example 3] In working example 2, set the 2nd layer to GaN which cm<sup>-3</sup>[ 1x10<sup>18</sup>]/-doped Si in the superlattice which constitutes the n side contact layer 12, and also. When the laser device which has the same structure as working example 2 was produced, the laser device which has the characteristic almost equivalent to working example 2 was obtained.

[0089][Working example 4] In working example 1, set the 2nd buffer layer 112 to GaN which cm<sup>-3</sup>[ 1x10<sup>17</sup>]/-doped Si, and grow up it 4 micrometers, and also. When the laser device which has the same structure as working example 1 was produced, it went up to threshold current density 2.9 kA/cm<sup>2</sup> and the threshold voltage 4.5V, but the life showed 50 hours or more.

[0090][Working example 5] The 1st layer that consists the n side contact layer 12 of n type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N which cm<sup>-3</sup>[ 2x10<sup>19</sup>]/-doped Si in working example 1



is grown up by 60-A thickness, Then, the 2nd layer that consists of GaN which  $\text{cm}^{-3}[1 \times 10^{19}]$ -doped Si is grown up by 40-A thickness, this is repeated successively, and it is considered as the superstructure of 2 micrometers of the total thickness. And 0.4 micrometer of n side clad layers 14 are grown up by the n type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N single which  $\text{cm}^{-3}[1 \times 10^{19}]$ -doped Si. When it was considered as the laser device which has the same structure as working example 1, it is threshold current density 3.2 kA/cm<sup>2</sup> and the threshold voltage 4.8V, and, as for the other structure, the life also showed 30 hours or more.

[0091][Working example 6] As compared with working example 1, following (1) differs from (2), and also working example 6 is constituted like working example 1.

(1) Stop only TMG after buffer layer 11 growth, and raise temperature to 1050 \*\*.

If it becomes 1050 \*\*, TMA, TMG, ammonia, and Silang will be used for material gas, The 1st layer that consists of n type aluminum<sub>0.2</sub>Ga<sub>0.8</sub>N which  $\text{cm}^{-3}[1 \times 10^{19}]$ -doped Si is grown up by 60-A thickness, then Silang and the 2nd layer that stops TMA and consists of undoped GaN are grown up by 40-A thickness. and 1st layer + 2nd layer + 1st layer + 2nd layer + ... as -- superlattice layers are constituted, respectively the 1st layer is laminated to 500 layers, the 2nd layer is

laminated alternately [ 500 layer ], and the n side contact layer 12 which consists of superlattice of 5 micrometers of the total thickness is formed.

(2) Next, grow up the crack prevention layer 13 which consists of  $\text{In}_{0.1}\text{Ga}_{0.9}\text{N}$  which  $\text{cm}^{-3}$  [  $5 \times 10^{18}$  ]-doped Si like working example 1 by 500-A thickness. And temperature shall be 1050 °C and the n side clad layer 14 which consists of n type  $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$  which  $\text{cm}^{-3}$  [  $5 \times 10^{18}$  ]-doped Si is grown up by 0.5 micrometer of thickness using TMA, TMG, ammonia, and Silang. Let tops be a laser device of working example 1, and a laser device which has the same structure from the next n side clad layer 14. That is, in the basic structure of Table 1, the n side contact layer 12 and the p side clad layer 19 are used as superlattice, and the laser device which makes 150 Å thickness of the p side contact layer 20 like working example 1 is produced. This laser device was threshold current density 3.2 kA/cm<sup>2</sup> and the threshold voltage 4.8V, 405-nm continuous oscillation was checked and the life also showed 30 hours or more.

[0092]When the thickness of p side contact layer of the LD element of the structure of working example 6 is changed one by one, the relation between the thickness of the p side contact layer and the threshold voltage of an LD element

is shown in drawing 3. As for this, p side contact layers are A (10 Å or less), B (10 Å), C (30 Å), and D from the left to order.

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## DESCRIPTION OF DRAWINGS

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[Brief Description of the Drawings]

[Drawing 1] It is a type section figure showing the composition of the nitride semiconductor device (LED element) of Embodiment 1 concerning this invention.

[Drawing 2] It is a type section figure showing the composition of the nitride semiconductor device (LD element) of Embodiment 2 concerning this invention.

[Drawing 3] It is a graph which shows the thickness of p side contact layer in the LD element of working example 1 concerning this invention, and a relation with threshold voltage.

[Drawing 4] It is a type section figure of the LD element of working example 26 concerning this invention.

[Explanations of letters or numerals]

1, 10 .... Substrate,

2, 11 .... Buffer layer

3, 12 .... n side contact layer,

13 .... Crack prevention layer,

14 .... N side clad layer (superlattice layers),

15 .... The n side light guide layer,

4, 16 .... Active layer,

17 .... Cap layer

18 .... The p side light guide layer,

5, 19 .... P side clad layer (superlattice layers),

6, 20 .... p side contact layer,

7, 21 .... p electrode,

8, 22 .... p pad electrode,

9, 23 .... n electrode,

24 .... n pad electrode,

25 .... Insulator layer,

101 .... GaN board,

112 .... The 2nd buffer layer,

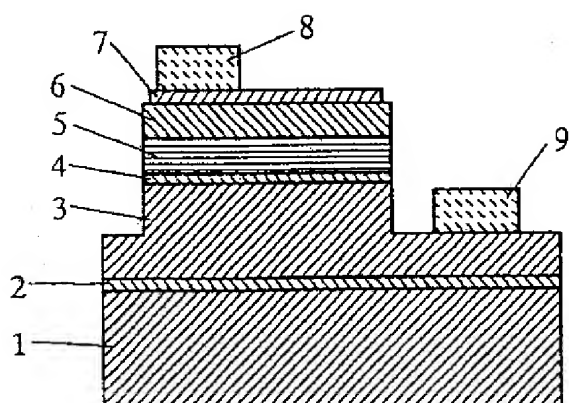
113 .... The 3rd buffer layer.

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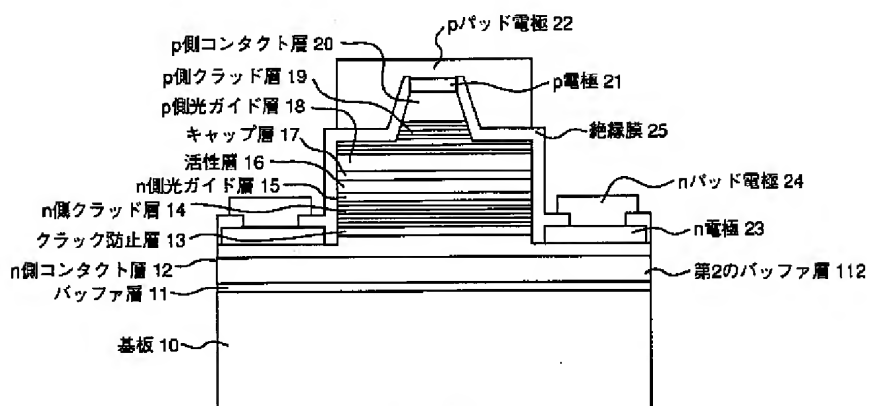
## DRAWINGS

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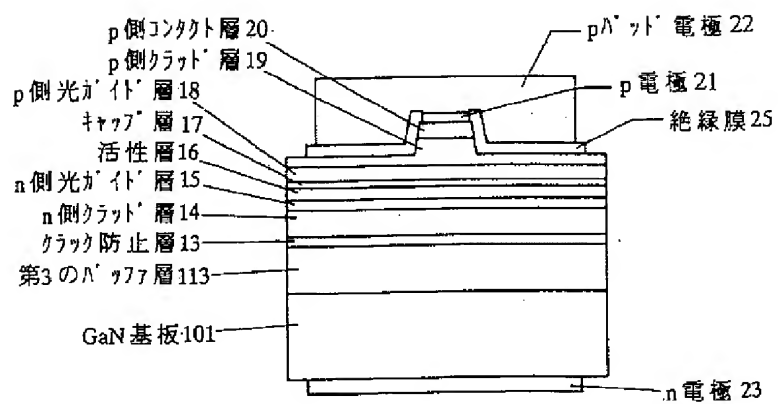
[Drawing 1]



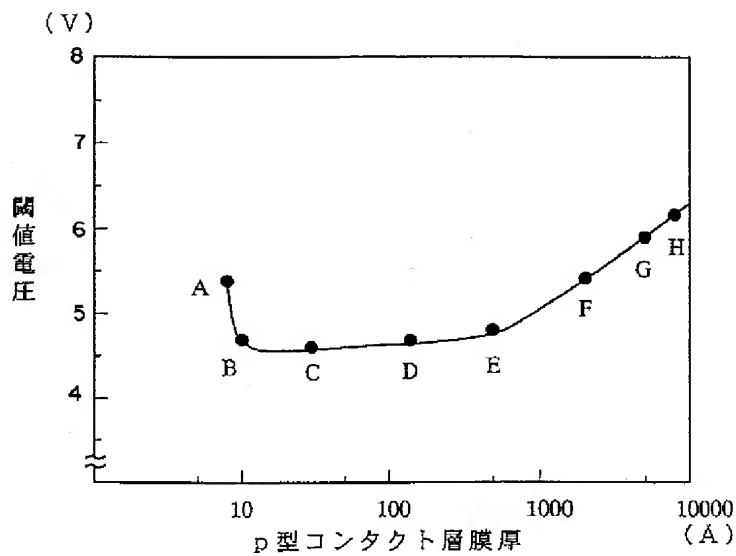
[Drawing 2]



[Drawing 4]



[Drawing 3]



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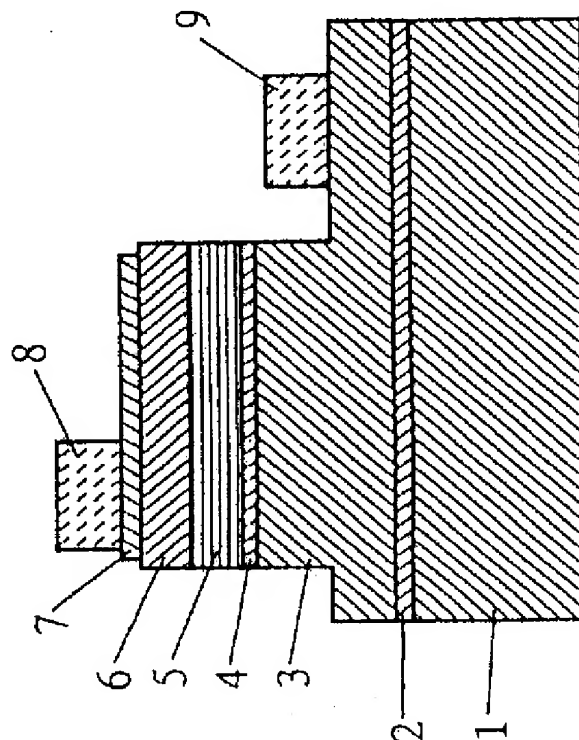
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(54)【発明の名称】 窒化物半導体素子

(57)【要約】

【課題】 電力効率のよい窒化物半導体素子を提供する。

【解決手段】 基板上に、n側コンタクト層、n側クラッド層及びn側光ガイド層が積層されたn型窒化物半導体層領域と、n側光ガイド層上に形成された窒化物半導体からなる活性層と、その活性層上に形成された、p側光ガイド層、p側クラッド層及びp側コンタクト層が積層されたp型窒化物半導体層領域とを有し、p側クラッド層を、100Å以上で1000Å以下の膜厚を有し、A1を含まない窒化物半導体からなる第1の層と、該第1の層と組成が異なりかつ100Å以上で1000Å以下の膜厚を有し、A1を含む窒化物半導体からなる第2の層とが積層された超格子層とした。



## 【特許請求の範囲】

【請求項 1】 基板上に、 $n$  側コンタクト層、 $n$  側クラッド層及び  $n$  側光ガイド層が積層された  $n$  型窒化物半導体層領域と、窒化物半導体からなる活性層と、 $p$  側光ガイド層、 $p$  側クラッド層及び  $p$  側コンタクト層が積層された  $p$  型窒化物半導体層領域とを有する窒化物半導体素子であって、

前記  $p$  側クラッド層は、 $10 \text{ \AA}$  以上で  $100 \text{ \AA}$  以下の膜厚を有し、 $A1$  を含まない窒化物半導体からなる第 1 の層と、該第 1 の層と組成が異なりかつ  $10 \text{ \AA}$  以上で  $100 \text{ \AA}$  以下の膜厚を有し、 $A1$  を含む窒化物半導体からなる第 2 の層とが積層された超格子層であることを特徴とする窒化物半導体素子。

【請求項 2】 前記第 1 の層及び前記第 2 の層の内の少なくとも一方に、 $p$  型不純物がドーピングされた請求項 1 記載の窒化物半導体素子。

【請求項 3】 前記第 1 の層及び前記第 2 の層にドーピングされた  $p$  型不純物の濃度が互いに異なる請求項 2 記載の窒化物半導体素子。

【請求項 4】 前記第 1 の層と前記第 2 の層とのバンドギャップエネルギーが互いに異なり、かつバンドギャップエネルギーが大きい層の不純物濃度を大きくした請求項 2 又は 3 記載の窒化物半導体素子。

【請求項 5】 基板上に、 $n$  側コンタクト層、 $n$  側クラッド層及び  $n$  側光ガイド層が積層された  $n$  型窒化物半導体層領域と、窒化物半導体からなる活性層と、 $p$  側光ガイド層、 $p$  側クラッド層及び  $p$  側コンタクト層が積層された  $p$  型窒化物半導体層領域とを有する窒化物半導体素子であって、

前記  $p$  側クラッド層及び前記  $n$  側クラッド層のうち少なくとも一つは、 $10 \text{ \AA}$  以上で  $100 \text{ \AA}$  以下の膜厚を有し、 $A1$  を含まない窒化物半導体からなる第 1 の層と、該第 1 の層と組成が異なりかつ  $10 \text{ \AA}$  以上で  $100 \text{ \AA}$  以下の膜厚を有し、 $A1$  を含む窒化物半導体からなる第 2 の層とが積層された超格子層であることを特徴とする窒化物半導体素子。

【請求項 6】 前記  $p$  側クラッド層が前記超格子層であり、前記第 1 の層及び前記第 2 の層の内の少なくとも一方に、 $p$  型不純物がドーピングされた請求項 5 の窒化物半導体素子。

【請求項 7】 前記第 1 の層及び前記第 2 の層にドーピングされた  $p$  型不純物の濃度が互いに異なる請求項 6 記載の窒化物半導体素子。

【請求項 8】 前記第 1 の層と前記第 2 の層とのバンドギャップエネルギーが互いに異なり、かつバンドギャップエネルギーが大きい層の不純物濃度を大きくした請求項 7 記載の窒化物半導体素子。

【請求項 9】 前記  $n$  側クラッド層が前記超格子層であり、前記第 1 の層及び前記第 2 の層の内の少なくとも一方に、 $n$  型不純物がドーピングされた請求項 5 の窒化物半導

体素子。

【請求項 10】 前記第 1 の層及び前記第 2 の層にドーピングされた  $n$  型不純物の濃度が互いに異なる請求項 9 記載の窒化物半導体素子。

【請求項 11】 前記第 1 の層と前記第 2 の層とのバンドギャップエネルギーが互いに異なり、かつバンドギャップエネルギーが大きい層の不純物濃度を大きくした請求項 10 記載の窒化物半導体素子。

【請求項 12】 前記第 2 の層が、式  $A1_Y Ga_{1-Y}N$  (ただし、 $0 < Y \leq 1$ ) であらわされる窒化物半導体である請求項 1～11 に記載の窒化物半導体素子。

【請求項 13】 前記超格子層において、前記第 1 の層が式  $In_x Ga_{1-x}N$  ( $0 \leq X \leq 1$ ) で表される窒化物半導体からなり、かつ前記第 2 の層が式  $A1_Y Ga_{1-Y}N$  (ただし、 $0 < Y \leq 1$ ) で表される窒化物半導体からなる請求項 12 に記載の窒化物半導体素子。

【請求項 14】 前記超格子層において、前記第 1 の層が式  $In_x Ga_{1-x}N$  ( $0 \leq X < 1$ ) で表される窒化物半導体からなり、かつ前記第 2 の層が式  $A1_Y Ga_{1-Y}N$  (ただし、 $0 < Y < 1$ ) で表される窒化物半導体からなる請求項 13 に記載の窒化物半導体素子。

【請求項 15】 前記第 1 の層及び前記第 2 の層がそれぞれ、 $70 \text{ \AA}$  以下の膜厚を有する窒化物半導体からなる請求項 1～14 のうちのいずれか 1 項に記載の窒化物半導体素子。

【請求項 16】 前記  $p$  側コンタクト層の膜厚が  $500 \text{ \AA}$  以下である請求項 1～15 のうちのいずれか 1 項に記載の窒化物半導体素子。

【請求項 17】 前記  $p$  側コンタクト層の膜厚がさらに、 $300 \text{ \AA}$  以下、 $10 \text{ \AA}$  以上である請求項 16 記載の窒化物半導体素子。

【請求項 18】 基板上に、 $n$  側コンタクト層、 $n$  側クラッド層及び  $n$  側光ガイド層が積層された  $n$  型窒化物半導体層領域と、窒化物半導体からなる活性層と、 $p$  側光ガイド層、 $p$  側クラッド層及び  $p$  側コンタクト層が積層された  $p$  型窒化物半導体層領域とを有する窒化物半導体素子であって、

前記  $n$  側クラッド層が、 $10 \text{ \AA}$  以上で  $100 \text{ \AA}$  以下の膜厚を有し、 $A1$  を含まない窒化物半導体からなる第 1 の層と、該第 1 の層と組成が異なりかつ  $10 \text{ \AA}$  以上で  $100 \text{ \AA}$  以下の膜厚を有し、 $A1$  を含む窒化物半導体からなる第 2 の層とが積層された超格子層であり、かつ前記  $p$  側クラッド層が、 $10 \text{ \AA}$  以上で  $100 \text{ \AA}$  以下の膜厚を有し、 $A1$  を含まない窒化物半導体からなる第 3 の層と、該第 3 の層と組成が異なりかつ  $10 \text{ \AA}$  以上で  $100 \text{ \AA}$  以下の膜厚を有し、 $A1$  を含む窒化物半導体からなる第 4 の層とが積層された超格子層であることを特徴とする窒化物半導体素子。

【請求項 19】 前記  $p$  側クラッド層及び該  $p$  側クラッド層より上に形成されている層において、共振方向に峰



状のリッジ部が形成された請求項 18 記載の窒化物半導体素子。

【請求項 20】 前記活性層は、インジウムを含む窒化物半導体を有する請求項 1～19 のうちのいずれか 1 項に記載の窒化物半導体素子。

【請求項 21】 前記窒化物半導体素子が、サファイア基板の C 面上に形成されている請求項 1～20 のうちのいずれか 1 項に記載の窒化物半導体素子。

【請求項 22】 前記窒化物半導体素子が、サファイア基板の C 面上に Si をドーブした GaN 層を成長させた後、サファイア基板を除去した GaN 基板上に形成されている請求項 1～20 のうちのいずれか 1 項に記載の窒化物半導体素子。

【請求項 23】 前記 n 側光ガイド層は GaN ある請求項 1～22 のうちのいずれか 1 項に記載の窒化物半導体素子。

【請求項 24】 前記 n 側光ガイド層は InGa<sub>N</sub>である請求項 1～22 のうちのいずれか 1 項に記載の窒化物半導体素子。

【請求項 25】 前記 p 側光ガイド層は GaN である請求項 1～24 のうちのいずれか 1 項に記載の窒化物半導体素子。

【請求項 26】 前記 p 側光ガイド層は InGa<sub>N</sub>である請求項 1～24 のうちのいずれか 1 項に記載の窒化物半導体素子。

【請求項 27】 前記窒化物半導体素子は、前記活性層に接して、Al を含む窒化物半導体よりなる p 側キャップ層を有し、その p 側キャップ層よりも活性層から離れた位置に、前記 p 側キャップ層よりもバンドギャップエネルギーが小さい p 側光ガイド層を有する請求項 1～26 のうちのいずれか 1 項に記載の窒化物半導体素子。

【発明の詳細な説明】

【0001】

【発明の属する技術分野】本発明は LED（発光ダイオード）、LD（レーザダイオード）等の発光素子、太陽電池、光センサー等の受光素子、又はトランジスタ等の電子デバイスに使用される窒化物半導体（ $\text{In}_x\text{Al}_y\text{Ga}_{1-x-y}\text{N}$ 、 $0 \leq x$ 、 $0 \leq y$ 、 $x+y \leq 1$ ）よりなる素子に関する。なお、本明細書において使用する一般式  $\text{In}_x\text{Ga}_{1-x}\text{N}$ 、 $\text{Al}_y\text{Ga}_{1-y}\text{N}$  等は単に窒化物半導体層の組成式を示すものであって、異なる層が例えば同一の一般式で示されていても、それらの層の X 値、Y 値が一致していることまで示すものではない。

【0002】

【従来の技術】窒化物半導体は高輝度青色 LED、純緑色 LED の材料として、フルカラー LED ディスプレイ、交通信号等で最近実用化されたばかりである。これらの各種デバイスに使用される LED は、n 型窒化物半導体層と p 型窒化物半導体層との間に、単一量子井戸構造（SQW: Single-Quantum-Well）の InGa<sub>N</sub>より

なる活性層が挟まれたダブルヘテロ構造を有している。青色、緑色等の波長は InGa<sub>N</sub> 活性層の In 組成比を増減することで決定されている。

【0003】また、本出願人は、最近この材料を用いてパルス電流下、室温での 410 nm のレーザ発振を世界で初めて発表した（例えば、Jpn.J.Appl.Phys. Vol35 (1996) pp.L74-76）。このレーザ素子はパルス幅 2 μs、パルス周期 2 ms の条件で、閾値電流 610 mA、閾値電流密度 8.7 kA/cm<sup>2</sup>、410 nm の発振を示す。さらにまた、閾値電流が低い改良したレーザ素子を、Appl.Phys.Lett., Vol.69, No.10, 2 Sep. 1996, p.1477-1479 において発表した。このレーザ素子は、p 型窒化物半導体層の一部にリッジストライプが形成された構造を有しており、パルス幅 1 μs、パルス周期 1 ms、デューティ比 0.1% で、閾値電流 187 mA、閾値電流密度 3 kA/cm<sup>2</sup>、410 nm の発振を示す。

【0004】

【発明が解決しようとする課題】窒化物半導体よりなる青色、緑色 LED は順方向電流（If）20 mA で、順方向電圧（Vf）が 3.4 V～3.6 V あり、GaAlAs 系の半導体よりなる赤色 LED に比べて 2 V 以上高いため、さらなる Vf の低下が望まれている。また、LD では閾値での電流、電圧が未だ高く、室温で連続発振させるためには、この閾値電流、電圧が下がるような、さらに電力効率の高い素子を実現する必要がある。

【0005】従って本発明の目的とするところは、主として窒化物半導体よりなる LD 素子の閾値での電流、電圧を低下させることにより連続発振を実現し、また LED 素子では Vf を低下させ、信頼性が高く、電力効率に優れた窒化物半導体素子を実現することにある。

【0006】

【課題を解決するための手段】本発明者らは、窒化物半導体素子について、活性層を挟んだ p 型層、及び／又は n 型層を改良すべく鋭意検討した結果、活性層を除く p 型層、及び／又は n 型層に超格子層を用いることにより、超格子層を用いた層の結晶性を良好にでき、前記問題を解決できることを新たに見だし本発明を成すに至った。

【0007】すなわち、本発明に係る第 1 の窒化物半導体素子は、基板上に、n 側コンタクト層、n 側クラッド層及び n 側光ガイド層が積層された n 型窒化物半導体層領域と、窒化物半導体からなる活性層と、p 側光ガイド層、p 側クラッド層及び p 側コンタクト層が積層された p 型窒化物半導体層領域とを有する窒化物半導体素子であって、前記 p 側クラッド層は、10 Å 以上で 100 Å 以下の膜厚を有し、Al を含まない窒化物半導体からなる第 1 の層と、該第 1 の層と組成が異なりかつ 10 Å 以上で 100 Å 以下の膜厚を有し、Al を含む窒化物半導体からなる第 2 の層とが積層された超格子層であることを特徴とする。これによって、前記超格子層からなる p

型窒化物半導体層の抵抗値を極めて低くできるので、窒化物半導体素子の電力効率を高くすることができる。また、本発明に係る第1の窒化物半導体素子において、前記超格子層は、100 Å以下の膜厚を有する窒化物半導体からなる第1の層と該第1の層と組成が異なりかつ100 Å以下の膜厚を有する窒化物半導体からなる第2の層とが積層されているので、前記超格子層の結晶性を良くできる。p型のクラッド層に超格子構造を適用することによる閾値電流、電圧を低げる効果は大きく、本発明では、閾値電流、電圧を顕著に低下させることができる。

【0008】本発明に係る第1の窒化物半導体素子では、前記第1の層及び前記第2の層の内の少なくとも一方に、p型不純物をドーピングすることが好ましく、前記第1の層及び前記第2の層にドーピングされたp型不純物の濃度は互いに異なっていることが好ましい。また、上記第1の窒化物半導体素子では、前記第1の層と前記第2の層とのバンドギャップエネルギーが互いに異なる場合、バンドギャップエネルギーが大きい層の不純物濃度を大きくすることが好ましい。

【0009】また、本発明に係る第2の窒化物半導体素子は、基板上に、n側コンタクト層、n側クラッド層及びn側光ガイド層が積層されたn型窒化物半導体層領域と、窒化物半導体からなる活性層と、p側光ガイド層、p側クラッド層及びp側コンタクト層が積層されたp型窒化物半導体層領域とを有する窒化物半導体素子であって、前記p側クラッド層及び前記n側クラッド層のうち少なくとも一つは、10 Å以上で100 Å以下の膜厚を有し、Alを含む窒化物半導体からなる第1の層と、該第1の層と組成が異なりかつ10 Å以上で100 Å以下の膜厚を有し、Alを含む窒化物半導体からなる第2の層とが積層された超格子層であることを特徴とする。

【0010】本発明に係る第2の窒化物半導体素子において、前記p側クラッド層が前記超格子層である場合には、前記第1の層及び前記第2の層の内の少なくとも一方に、p型不純物をドーピングすることが好ましく、また、前記第1の層及び前記第2の層にドーピングされたp型不純物の濃度は互いに異なっていることが好ましい。本発明に係る第2の窒化物半導体素子では、前記第1の層と前記第2の層とのバンドギャップエネルギーが互いに異なる場合、バンドギャップエネルギーが大きい層の不純物濃度を大きくすることが好ましい。

【0011】本発明に係る第2の窒化物半導体素子において、前記n側クラッド層が前記超格子層である場合には、前記第1の層及び前記第2の層の内の少なくとも一方にn型不純物をドーピングすることが好ましく、また、記第1の層及び前記第2の層、にドーピングされたn型不純物の濃度が互いに異なっていることが好ましい。この際、前記第1の層と前記第2の層とのバンドギャップエネル

ギーが互いに異なる場合、かつバンドギャップエネルギーが大きい層の不純物濃度を大きくすることが好ましい。

【0012】また、本発明に係る第3の窒化物半導体素子は、基板上に、n側コンタクト層、n側クラッド層及びn側光ガイド層が積層されたn型窒化物半導体層領域と、窒化物半導体からなる活性層と、p側光ガイド層、p側クラッド層及びp側コンタクト層が積層されたp型窒化物半導体層領域とを有する窒化物半導体素子であって、前記n側クラッド層が、10 Å以上で100 Å以下の膜厚を有し、Alを含まない窒化物半導体からなる第1の層と、該第1の層と組成が異なりかつ10 Å以上で100 Å以下の膜厚を有し、Alを含む窒化物半導体からなる第2の層とが積層された超格子層であり、かつ前記p側クラッド層が、10 Å以上で100 Å以下の膜厚を有し、Alを含まない窒化物半導体からなる第3の層と、該第3の層と組成が異なりかつ10 Å以上で100 Å以下の膜厚を有し、Alを含む窒化物半導体からなる第4の層とが積層された超格子層であることを特徴とする。

【0013】上記第3の窒化物半導体素子では、前記p側クラッド層及び該p側クラッド層より上に形成されている層において、共振方向に峰状のリッジ部を形成するようにしてもよい。

【0014】本発明に係る第1～第3の窒化物半導体素子では、前記活性層は、インジウムを含む窒化物半導体を有していてもよい。また、前記第1～第3の窒化物半導体素子は、サファイア基板のC面上に形成するようにしてもよいし、前記第1～第3の窒化物半導体素子は、サファイア基板のC面上にSiをドーピングしたGaN層を成長させた後、サファイア基板を除去したGaN基板上に形成するようにしてもよい。前記第1～第3の窒化物半導体素子において、前記n側光ガイド層はGaNであってもよいし、InGaNであってもよい。前記第1～第3の窒化物半導体素子において、前記p側光ガイド層はGaNであってもよいし、InGaNであってもよい。前記第1～第3の窒化物半導体素子において、前記活性層に接して、Alを含む窒化物半導体よりなるp側キャップ層を有し、そのp側キャップ層よりも活性層から離れた位置に、前記p側キャップ層よりもバンドギャップエネルギーが小さいp側光ガイド層を設けるようにすることが好ましい。

【0015】また、本発明の第1～第3の窒化物半導体素子において、超格子層を $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0 \leq X \leq 1$ ) からなる第1の層と、 $\text{Al}_y\text{Ga}_{1-y}\text{N}$  ( $0 \leq Y \leq 1, X=Y \neq 0$ ) からなる第2の層とを積層することにより構成すると、一般式 $\text{Al}_y\text{Ga}_{1-y}\text{N}$ 、及び $\text{In}_x\text{Ga}_{1-x}\text{N}$ で表される窒化物半導体は結晶性の良い半導体層が得られることから、結晶欠陥の少ない層を形成できる。これにより、窒化物半導体全体の結晶性

が良くなり、該素子の出力を向上（電力効率の向上）、該素子がLED素子又はLD素子である場合には、 $V_f$ 、閾値電流、電圧等を低くすることができる。尚、本発明の第1～第3の窒化物半導体素子では、さらに結晶欠陥の少ない層を形成するために、前記超格子層において、前記第1の層が式  $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0 \leq X < 1$ ) で表される窒化物半導体からなり、かつ前記第2の層が式  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  ( $0 < Y < 1$ ) で表される窒化物半導体からなることがさらに好ましい。

【0016】また、本発明の第1～第3の窒化物半導体素子において、前記第1の層、及び第2の層の膜厚は、上述のように、70 Å以下であることが好ましいが、さらに好ましくは40 Å以下に設定する。また、本発明では、前記第1の層、及び第2の層の膜厚は10 Å以上に設定する。この範囲内に設定することにより、従来では成長させにくかった  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  ( $0 < Y \leq 1$ ) 等の窒化物半導体層が結晶性良く形成することができる。特に、p電極と活性層との間にあるp型窒化物半導体層の内の少なくとも一層、及び／又はn電極が形成される電流注入層としてのn側コンタクト層と活性層との間にあるn型窒化物半導体層の内の少なくとも一層を超格子層とする場合に、その超格子層を構成する第1の層、及び第2の層を前記膜厚に設定することによる効果が大きい。

【0017】また、本発明の第1～第3の窒化物半導体素子においては、p電極を形成するためのp側コンタクト層を備え、該p側コンタクト層の膜厚を500 Å以下に設定することが好ましい。このように、p側コンタクト層を薄く形成することにより、該p側コンタクト層の厚さ方向の抵抗値を下げるができる。本発明では、300 Å以下に設定することがさらに好ましい。また、該p側コンタクト層の膜厚の下限は、該p型コンタクト層の下の半導体層を露出させないように、10 Å以上に設定することが好ましい。

【0018】また、本発明では、基板上に第1のバッファ層を形成し、その上に膜厚0.1 μm以上の窒化物半導体からなる第2のバッファ層を形成して、該第2のバッファ層上に、n型不純物がドーピングされた窒化物半導体からなるn側コンタクト層を形成することが好ましい。これによって、キャリア濃度が大きく結晶性のよいn側コンタクト層を形成することができる。さらに結晶性のよい、前記第2バッファ層を形成するために、前記第2のバッファ層の不純物濃度が、前記n側コンタクト層に比較して低濃度であることが好ましい。

【0019】なお、本発明において、導電型を決定する不純物としては、窒化物半導体にドーピングされる周期律表第4A族、4B族、第6A族、第6B族に属するn型不純物と、1A、1B族、2A族、2B族に属するp型不純物とがある（以下、本明細書において、適宜n型不純物、p型不純物と記する。）。さらに、上述したよう

に、第1の層と第2の層とでバンドギャップエネルギーが異なる場合には、バンドギャップエネルギーの大きい方の層の不純物濃度を大きくすることが望ましい。これによって、p型窒化物半導体層側に超格子層を形成した場合の変調ドーピングによる高出力化が期待できる。本発明では、n側コンタクト層が超格子層であってもよい。n側コンタクト層である超格子層を構成する2つの層でバンドギャップエネルギーが互いに異なり、バンドギャップエネルギーの大きい方の層の不純物濃度を大きくすることにより、後述するHEMTに類似したような効果により電力効率を向上させることができる。例えば、レーザ素子では、さらに閾値電圧、閾値電流が低下する傾向にある。

#### 【0020】

【発明の実施の形態】以下、図面を参照して本発明に係る実施の形態の窒化物半導体素子について説明する。  
実施形態1. 図1は、本発明に係る実施形態1の窒化物半導体素子の構造を示す模式的な断面図であり、該窒化物半導体素子は、基本的な構造として、サファイアよりなる基板1の上に、GaNよりなるバッファ層2、Siドーピングn型GaNよりなるn側コンタクト層3、単一量子井戸構造のInGaNよりなる活性層4、互いに組成の異なる第1の層と第2の層とが積層された超格子層よりなるp側クラッド層5、MgドーピングGaNよりなるp側コンタクト層6とが順に積層されているLED素子である。なお、実施形態1の窒化物半導体素子において、p側コンタクト層6表面のほぼ全面には、透光性の全面電極7が形成され、全面電極7の表面にはボンディング用のp電極8が設けられており、さらにp側コンタクト層6より窒化物半導体層の一部をエッチング除去して露出されたn側コンタクト層2の表面にはn電極9が設けられている。

【0021】ここで、実施形態1の窒化物半導体素子は、例えばp型不純物としてMgをドーピングした  $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0 \leq X \leq 1$ ) よりなる膜厚30オングストローム (Å) の第1の層と、同じくp型不純物としてMgを第1の層と同量でドーピングしたp型  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  ( $0 \leq Y \leq 1$ ) よりなる膜厚30オングストロームの第2の層とが積層された超格子層で構成された低い抵抗値を有するp側クラッド層5を備えているので、 $V_f$ を低くできる。このように超格子層をp層側に形成する場合は、Mg、Zn、Cd、Be等のp型不純物を第1の層、及び／又は第2の層にドーピングしてp型の導電型を有する超格子層とする。積層順としては、第1+第2+第1・・・、若しくは第2+第1+第2・・・の順でも良く、少なくとも合計2層以上積層する。

【0022】尚、超格子層を構成する窒化物半導体よりなる第1の層及び第2の層は、  $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0 \leq X \leq 1$ ) よりなる層及び  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  ( $0 \leq Y \leq 1$ ) よりなる層に限定されるわけではなく、互いに組

成が異なる窒化物半導体で構成されていれば良い。また、第1の層と第2の層とのバンドギャップエネルギーが異なっている、同一でもかまわない。例えば、第1の層を  $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0 \leq x \leq 1$ ) で構成し、第2の層を  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  ( $0 < y \leq 1$ ) で構成すると、第2の層のバンドギャップエネルギーが必ず第1の層よりも大きくなるが、第1の層を  $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0 \leq x \leq 1$ ) で構成し、第2の層を  $\text{In}_z\text{Al}_{1-z}\text{N}$  ( $0 < z \leq 1$ ) で構成すれば、第1の層と第2の層とは組成が異なるがバンドギャップエネルギーが同一の場合もあり得る。また第1の層を  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  ( $0 \leq y \leq 1$ ) で構成し、第2の層を  $\text{In}_z\text{Al}_{1-z}\text{N}$  ( $0 < z \leq 1$ ) で構成すれば、同様に第1の層と第2の層とは組成が異なるがバンドギャップエネルギーが同一の場合もあり得る。すなわち、本発明は、後述する作用を有する超格子層であれば、第1の層と第2の層のバンドギャップエネルギーが同じであっても、異なっている、異なる極めて薄い層が積層されたものであって、各層の厚さが十分薄いために、格子不整に伴う欠陥が発生することなく積層された層のことをいい、量子井戸構造を含む広い概念である。また、この超格子層は、内部に欠陥は有しないが、通常、格子不整に伴う歪みを有するので歪み超格子とも呼ばれる。本発明において、第1の層、第2の層のN(窒素)を一部As、P等のV族元素で置換してもNが存在している限り窒化物半導体に含まれる。

【0023】本発明において、超格子層を構成する第1の層、第2の層の膜厚は、100オングストロームよりも厚いと、第1の層及び第2の層が弾性歪み限界以上の膜厚となり、該膜中に微少なクラック、あるいは結晶欠陥が入りやすくなるので、100オングストローム以下の膜厚に設定することが好ましい。また、第1の層、第2の層の膜厚の下限は特に限定されず1原子層以上であればよい。しかしながら、本発明では、第1の層、第2の層の膜厚は、100オングストロームであると窒化物半導体の臨界(弾性歪み)限界膜厚に十分に達しておらず、弾性歪み限界膜厚以下にして窒化物半導体の結晶欠陥をより少なくするため70オングストローム以下に設定することが好ましく、さらに好ましくはより薄く設定し、40オングストローム～10オングストロームに設定することが最も好ましい。また、本発明では、10オングストローム以下(1原子層又は2原子層)に設定してもよいが、10オングストローム以下に設定すると、例えば、500オングストローム以上の膜厚のクラッド層を超格子層で形成する場合、積層数が多くなり、製造工程上、形成時間及び手間がかかるので、第1の層、第2の層の膜厚は、10オングストロームより厚く設定することが好ましい。

【0024】図1に示す本実施形態1の窒化物半導体素

子の場合、超格子層よりなるp型クラッド層5は、活性層4と電流注入層であるp側コンタクト層6との間に形成されて、キャリア閉じ込め層として作用している。このように、特に超格子層をキャリア閉じ込め層とする場合には、超格子層の平均バンドギャップエネルギーを活性層よりも大きくする必要がある。窒化物半導体では、AlN、AlGaN、InAlN等のAlを含む窒化物半導体が、比較的大きなバンドギャップエネルギーを有するので、キャリア閉じ込め層としてこれらの層が用いられる。しかし、従来のようにAlGaN単一で厚膜を成長させると結晶成長中にクラックが入りやすい性質を有している。

【0025】そこで、本発明では、超格子層の第1の層、及び第2の層の内の少なくとも一方を少なくともAlを含む窒化物半導体、好ましくは  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  ( $0 < y \leq 1$ ) を弾性歪み限界以下の膜厚で形成して超格子層を構成することにより、クラックの少ない非常に結晶性の良い超格子層を成長形成させ、しかもバンドギャップエネルギーが大きな層を形成している。この場合さらに好ましくは、第1の層にAlを含まない窒化物半導体層を100オングストローム以下の膜厚で成長させると、Alを含む窒化物半導体よりなる第2の層を成長させる際のバッファ層としても作用し、第2の層にクラックを入りにくくする。そのため第1の層と第2の層とを積層してもクラックのない結晶性のよい超格子層を形成できる。従って、本実施形態1では、超格子層を  $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0 \leq x \leq 1$ ) からなる第1の層(第2の層)と  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  ( $0 \leq y \leq 1, x \neq y = 0$ ) からなる第2の層(第1の層)とすることが好ましい。

【0026】また、本実施形態1の窒化物半導体素子において、超格子層であるp側クラッド層5を構成する第1の層及び第2の層の内の少なくとも一方の層には、キャリア濃度を調整するために、該層の導電型をp型に設定するp型の不純物がドーピングされることが好ましい。また、第1の層と第2の層とにp型の不純物をドーピングする場合、第1の層と第2の層とで異なる濃度でドーピングしてもよく、さらに、第1の層と第2の層とのバンドギャップエネルギーが異なる場合には、バンドギャップエネルギーが大きな層の方を高濃度とすることが望ましい。なぜなら、第1の層、第2の層にそれぞれ異なる濃度で不純物をドーピングすると、変調ドーピングによる量子効果によって、一方の層のキャリア濃度が実質的に高くなり超格子層全体の抵抗値を低下させることができるからである。このように、本発明では、第1の層と、第2の層の両方に不純物を異なる濃度でそれぞれドーピングしても良いし、第1の層、第2の層のいずれか一方に不純物をドーピングしても良い。

【0027】なお、第1の層及び第2の層にドーピングされる不純物濃度は、特に本発明はこれに限定されないが、

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 $p$ 型不純物で通常、 $1 \times 10^{16} / \text{cm}^3 \sim 1 \times 10^{22} / \text{cm}^3$ 、さらに好ましくは $1 \times 10^{17} / \text{cm}^3 \sim 1 \times 10^{21} / \text{cm}^3$ 、最も好ましくは $1 \times 10^{18} / \text{cm}^3 \sim 2 \times 10^{20} / \text{cm}^3$ の範囲に調整することが望ましい。 $1 \times 10^{16} / \text{cm}^3$ よりも少ないと $V_f$ 、閾値電圧を低下させる効果が得られにくく、 $1 \times 10^{22} / \text{cm}^3$ よりも多いと超格子層の結晶性が悪くなる傾向にあるからである。また $n$ 型不純物も同様の範囲に調整することが望ましい。理由は同じである。

【0028】しかしながら、本発明では、超格子層には、第1の層及び第2の層に導電型を決定する不純物がドーピングされていなくてもよい。この不純物がドーピングされない超格子層は、 $n$ 型窒化物半導体層領域であれば活性層と基板との間におけるいずれの層であってもよく、一方、 $p$ 型窒化物半導体層領域であれば、キャリア閉じ込め層（光閉じ込め層）と、活性層との間におけるいずれの層であってもよい。

【0029】以上のように構成された超格子層は、第1の層、及び第2の層を弾性歪み限界以下の膜厚にして積層して形成しているので、結晶の格子欠陥を低下させることができ、かつ微少なクラックを減少させることができ、結晶性を飛躍的に良くすることができる。この結果、結晶性をあまり損なうことなく、不純物のドーピング量を多くでき、これによって、 $n$ 型窒化物半導体層、 $p$ 型窒化物半導体層のキャリア濃度を増加させることができ、かつ該キャリアが結晶欠陥によって散乱されることなく移動できるので、超格子構造を有しない $p$ 型又は $n$ 型の窒化物半導体に比較して抵抗率を1桁以上低くすることができる。

【0030】従って、本実施形態1の窒化物半導体素子（LED素子）では、従来、低抵抗な窒化物半導体層を得ることが困難であった $p$ 層側（ $p$ 型半導体層領域（ $p$ 型クラッド層5と $p$ 型コンタクト層6とからなる領域））の $p$ 型クラッド層5を超格子層を用いて形成して、該 $p$ 型クラッド層5の抵抗値を低くすることにより、 $V_f$ を低くすることができる。つまり、 $p$ 型窒化物半導体は、 $p$ 型結晶が非常に得られにくい半導体であり、得られたとしても、 $n$ 型窒化物半導体に比べて、通常抵抗率が2桁以上高い。そのため $p$ 型の超格子層を $p$ 層側に形成することにより、超格子層で構成された $p$ 型層を極めて低抵抗にすることができ、 $V_f$ の低下が顕著に現れる。従来、 $p$ 型結晶を得るため技術として、 $p$ 型不純物をドーピングした窒化物半導体層をアニーリングして、水素を除去することにより $p$ 型の窒化物半導体を作製する技術が知られている（特許第2540791号）。しかし、 $p$ 型の窒化物半導体が得られたといってもその抵抗率は、数 $\Omega \cdot \text{cm}$ 以上もある。そこで、この $p$ 型層を $p$ 型の超格子層とすることにより結晶性が良くなり、我々の検討によると、該 $p$ 層の抵抗率を従来に比較して、1桁以上低くすることができ、 $V_f$ の低下させ

る効果が顕著に現れる。

【0031】また、本実施形態1では、前記のように好ましくは第1の層（第2の層）を $\text{In}_x \text{Ga}_{1-x} \text{N}$ （ $0 \leq x \leq 1$ ）とし、第2の層（第1の層）を $\text{Al}_y \text{Ga}_{1-y} \text{N}$ （ $0 \leq y \leq 1$ 、 $x \neq y = 0$ ）で構成することにより、結晶性のよいクラックのない超格子層を形成することができるので、素子寿命を向上させることができる。

【0032】次に、我々が以前に出願した特許公報を含む公知文献に開示された従来例と本発明とを比較して説明する。まず、本発明に類似した技術として、我々は先に特開平8-228048号を提案した。この技術は活性層を挟む $n$ 型クラッド層の外側、及び／又は $p$ 型クラッド層の外側（つまり活性層からより離れた側）にレーザ光の光反射膜として $\text{AlGaIn}$ 、 $\text{GaIn}$ 、 $\text{InGaIn}$ 等よりなる多層膜を形成する技術である。この技術は光反射膜として多層膜を形成するので、その各層の膜厚が $\lambda / 4n$ （ $n$ :窒化物半導体の屈折率、 $\lambda$ :波長）で設計されるため非常に厚い。従って多層膜の各膜厚が弾性歪み限界以下の膜厚ではない。また、USP 5, 146, 465号には活性層を $\text{Al}_x \text{Ga}_{1-x} \text{N} / \text{Al}_y \text{Ga}_{1-y} \text{N}$ よりなるミラーで挟んだ構造のレーザ素子が記載されている。この技術も前技術と同様に $\text{AlGaIn} / \text{AlGaIn}$ をミラーとして作用させるために、各層の膜厚を厚くしなければならない。さらに $\text{AlGaIn}$ のような硬い半導体をクラックなしに何層も積層することは非常に難しい。

【0033】一方、本実施形態では超格子層を構成するように第1と第2の層の各膜厚を、設定（好ましくは、両方とも100オングストローム以下と臨界膜厚以下に設定する。）しており、前記技術とは異なる。本発明では超格子層を構成する窒化物半導体の歪み超格子による効果を利用し、結晶性を向上させて、 $V_f$ を低下させている。

【0034】さらに、特開平5-110138、特開平5-110139号公報には薄膜の $\text{AlIn}$ と $\text{GaIn}$ とを積層して $\text{Al}_y \text{Ga}_{1-y} \text{N}$ の結晶を得る方法が記載されている。この技術は、所定の混晶比の $\text{Al}_y \text{Ga}_{1-y} \text{N}$ の混晶を得るために、数十オングストロームの膜厚の $\text{AlIn}$ 、 $\text{GaIn}$ を積層する技術であって本発明の技術とは異なる。しかも $\text{InGaIn}$ よりなる活性層を有していないので、超格子層にクラックが入りやすい。また、特開平6-21511号、6-268257号公報では $\text{GaIn}$ と $\text{InGaIn}$ 、若しくは $\text{InGaIn}$ と $\text{InGaIn}$ とを積層した多重量子井戸構造の活性層を有するダブルヘテロ構造の発光素子が記載されている。本発明では活性層以外の層を多重量子井戸構造とする技術であり、この技術とも異なる。

【0035】さらに本発明の素子では $\text{InGaIn}$ のような、少なくともインジウムを含む窒化物半導体を活性層



に備える場合に、超格子の効果が顕著に現れる。InGa<sub>N</sub>活性層はバンドギャップエネルギーが小さく窒化物半導体素子の活性層としては最も適している。そのためIn<sub>x</sub>Ga<sub>1-x</sub>Nと、Al<sub>y</sub>Ga<sub>1-y</sub>Nよりなる超格子層を、活性層を挟設する層として形成すると、活性層とバンドギャップエネルギー差、屈折率差を大きくできるため、該超格子層がレーザ素子を実現する際に非常に優れた光閉じ込め層として動作する（実施形態2の窒化物半導体素子に適用）。さらにInGa<sub>N</sub>は結晶の性質が他のAlGa<sub>N</sub>のようなAlを含む窒化物半導体に比べて柔らかいので、InGa<sub>N</sub>を活性層とすると、積層した各窒化物半導体層全体にクラックが入りにくくなる。逆にAlGa<sub>N</sub>のような窒化物半導体を活性層とすると、その結晶の性質が硬いために結晶全体にクラックが入りやすくなる傾向にある。

【0036】さらにp側コンタクト層の膜厚を500オングストローム以下、さらに好ましくは300オングストローム以下、最も好ましくは200オングストローム以下に調整することが望ましい。なぜなら、上述したように抵抗率が数Ω・cm以上もあるp型窒化物半導体層の膜厚を500オングストローム以下に調整することにより、さらに抵抗率を下げることができるため、閾値での電流、電圧が低下する。またp型層から除去される水素の量を多くすることができ、さらに抵抗率を低下させることができる。

【0037】以上、詳述したように、本実施の形態1の窒化物半導体素子では、p型クラッド層5を第1の層と第2の層とが積層された超格子層で構成しているので、該p型クラッド層5を極めて低抵抗にでき、該素子のV<sub>f</sub>を低くできる。

【0038】以上の実施形態1では、p側クラッド層5に超格子層を用いたが、本発明はこれに限らず、p側コンタクト層6にp型の超格子層を用いてもよい。すなわち、電流（正孔）が注入されるp側コンタクト層6も例えばIn<sub>x</sub>Ga<sub>1-x</sub>Nよりなる第1の層と、Al<sub>y</sub>Ga<sub>1-y</sub>Nよりなる第2の層とが積層されたp型の超格子層とすることもできる。p型コンタクト層6を超格子層として、第1の層のバンドギャップエネルギーが第2の層よりも小さい場合、バンドギャップエネルギーが小さいIn<sub>x</sub>Ga<sub>1-x</sub>Nよりなる第1の層を最表面にしてp電極と接触する層とすることが好ましく、これによって、p電極との接触抵抗が小さくなり好ましいオーミックが得られる。これはバンドギャップエネルギーが小さい第1の層の方が、第2の層よりもキャリア濃度の高い窒化物半導体層が得られやすい傾向にあるからである。また、本発明では、p型窒化物半導体層領域に、上述のp側クラッド層及びp側コンタクト層以外のp型窒化物半導体層をさらに形成する場合は、該p型窒化物半導体層を超格子層で構成してもよい。

【0039】以上の実施形態1では、p側クラッド層5

に超格子層を用いたが、本発明はp型窒化物半導体層領域に限らず、n型窒化物半導体領域のn側コンタクト層3にn型の超格子層を用いてもよい。このように、n側コンタクト層3を超格子層とする場合は、例えば、Si、Ge等のn型不純物を第1の層及び／又は第2の層にドーピングして、n型の導電性を有する超格子層を基板1と活性層4との間にn型コンタクト層3として形成することができる。この場合、特にn型コンタクト層3を不純物濃度が異なる超格子層とすると横方向の抵抗値が低下して、LDでは閾値電圧、電流が低下する傾向にあることが確認された。

【0040】これは、バンドギャップエネルギーの大きな層の方に、多くn型不純物をドーピングした超格子層をn層側のコンタクト層として形成した場合について、以下のようなHEMT（High-Electron-Mobility-Transistor）に類似した作用が出現した効果が推察される。n型不純物がドーピングされたバンドギャップの大きい第1の層（第2の層）と、バンドギャップが小さいアンドープ（undoped）；以下、不純物がドーピングされていない状態をアンドープというの第2の層（第1の層）とを積層した超格子層では、n型不純物を添加した層と、アンドープの層とのヘテロ接合界面で、バンドギャップエネルギーの大きな層側が空乏化し、バンドギャップエネルギーの小さな層側の厚さ（100オングストローム）前後の界面に電子（二次元電子ガス）が蓄積する。この二次元電子ガスがバンドギャップエネルギーの小さな層側にできるので、電子が走行するときに不純物による散乱を受けないため、超格子層の電子の移動度が高くなり、抵抗率が低下すると推察される。

【0041】また、本発明において、n型窒化物半導体層領域にn側のクラッド層を設ける場合は、該n側のクラッド層を超格子層としてもよい。n型窒化物半導体層領域にn側コンタクト層及びn側クラッド層以外のn型窒化物半導体層を形成する場合は、該n型窒化物半導体層を超格子層としてもよい。しかし、n型窒化物半導体層領域に超格子層からなる窒化物半導体層を設ける場合、キャリア閉じ込め層としてのn側クラッド層、若しくは電流（電子）が注入されるn側コンタクト層3を超格子構造とすることが望ましいことはいうまでもない。

【0042】このように、超格子層を活性層4と基板1との間のn型窒化物半導体層領域に設ける場合、超格子層を構成する第1の層、第2の層には不純物をドーピングしなくても良い。なぜなら窒化物半導体はアンドープでもn型になる性質があるからである。但し、n層側に形成する場合においても上述のように、第1の層、第2の層にSi、Ge等のn型不純物をドーピングして、不純物濃度の差を設ける方が望ましい。

【0043】以上のように、超格子層をn型窒化物半導体層領域に形成した場合の効果は、超格子層をp型窒化物半導体層領域に設けた場合と同様に、結晶性の向上が

挙げられる。詳細に説明すると、ヘテロ接合を有する窒化物半導体素子の場合、通常n型、p型のキャリア閉じ込め層は、活性層よりもバンドギャップエネルギーが大きいAlGaInで構成される。AlGaInは結晶成長が非常に難しく、例えば単一組成で0.5 μm以上の膜厚で成長させようとする、結晶中にクラックが入りやすくなる性質がある。しかしながら、本発明のように第1の層と、第2の層とを弾性歪み限界以下の膜厚で積層して超格子層とすると、単一の第1の層、第2の層のみで結晶性の良いものが得られるため、全体を膜厚の厚い超格子層としても結晶性が良いままでクラッド層が成長できる。そのため全体の窒化物半導体の結晶性が良くなってn型領域の移動度が大きくなるので、その超格子層をクラッド層とした素子でV<sub>f</sub>が低下する。さらに、超格子層にSi、Geの不純物をドーピングして、超格子層をコンタクト層とした場合には前記したHEMTに類似した効果が顕著に現れてくるようになると思われる、閾値電圧、V<sub>f</sub>をさらに低下させることができる。

【0044】このように、本発明において、超格子層は、活性層を挟設するn型領域又はp型領域に形成されるキャリア閉じ込め層としてのクラッド層、活性層の光ガイド層、若しくは電極が接して形成される電流注入層として用いられるため、超格子層を構成する窒化物半導体の平均バンドギャップエネルギーが活性層よりも大きくなるように調整することが望ましい。

【0045】実施形態2. 次に、本発明に係る実施形態2について説明する。図2は、本発明に係る実施形態2の窒化物半導体素子の構造を示す模式的な断面図（レーザ光の共振方向に垂直な断面）であり、該窒化物半導体素子は、例えば、C面を主面とするサファイヤ等の基板10上に、n型窒化物半導体層領域（n側コンタクト層12、クラック防止層13、n側クラッド層14及びn側光ガイド層15からなる。）とp型窒化物半導体領域（キャップ層17、p側光ガイド層18、p側クラッド層19及びp側コンタクト層20からなる。）とによって挟設された窒化物半導体からなる活性層16を備えた窒化物半導体レーザダイオード素子である。

【0046】ここで、本実施形態2の窒化物半導体素子は、n型窒化物半導体層領域におけるn側クラッド層14を超格子層で形成し、かつp型窒化物半導体領域におけるp側クラッド層19を超格子層で形成することにより、LD素子である窒化物半導体素子の閾値電圧を低く設定している。以下この図2を参照して本発明に係る実施形態2の窒化物半導体素子について詳細に説明する。

【0047】この実施形態2の窒化物半導体素子においては、まず、基板10上にバッファ層11と第2のバッファ層112を介してn側コンタクト層12が形成され、さらにn側コンタクト層12上に、クラック防止層13、n側クラッド層14及びn側光ガイド層15が積層されて、n型窒化物半導体層領域が形成される。尚、

クラック防止層13の両側に露出されたn側コンタクト層12の表面にはそれぞれ、n側コンタクト層12とオーミック接触するn側電極23が形成され、該n側電極23上には、例えば、ワイヤーボンディング用のn側パッド電極が形成される。そして、n側光ガイド層15上に窒化物半導体からなる活性層16が形成され、さらに該活性層16上に、キャップ層17、p側光ガイド層18、p側クラッド層19及びp側コンタクト層20が積層されてp型窒化物半導体層領域が形成される。さらに、p側コンタクト層20上に該p側コンタクト層20とオーミック接触するp側電極21が形成され、該p側電極21上には、例えば、ワイヤーボンディング用のp側パッド電極が形成される。なお、p側コンタクト層20とp側クラッド層19の上部とによって、共振方向に長く伸びた峰状のリッジ部が構成され、該リッジ部を形成することによって、活性層16において、光りを幅方向（共振方向に直交する方向）に閉じ込め、リッジ部（ストライプ状の電極）に垂直な方向で劈開された劈開面を用いて、リッジ部の長手方向に共振する共振器を製作してレーザ発振させる。

【0048】次に、実施形態2の窒化物半導体素子の各構成要素について説明する。

（基板10）基板10にはC面を主面とするサファイヤの他、R面、A面を主面とするサファイヤ、その他、スピネル（MgAl<sub>2</sub>O<sub>4</sub>）のような絶縁性の基板の他、SiC（6H、4H、3Cを含む）、ZnS、ZnO、GaAs、GaN等の半導体基板を用いることができる。

【0049】（バッファ層11）バッファ層11は、例えばAlN、GaN、AlGaIn、InGaIn等を900℃以下の温度で成長させて、膜厚数十オングストローム〜数百オングストロームに形成する。このバッファ層11は、基板と窒化物半導体との格子定数不正を緩和するために形成するが、窒化物半導体の成長方法、基板の種類等によっては省略することも可能である。

【0050】（第2のバッファ層112）第2のバッファ層112は、前記バッファ層11の上に、前記バッファ層よりも高温で成長させた単結晶の窒化物半導体よりなる層であり、バッファ層11よりも厚膜を有する。この第2のバッファ層112は次に成長させるn側コンタクト層12よりもn型不純物濃度が少ない層とするか、若しくはn型不純物をドーピングしない窒化物半導体層、好ましくはGaN層とすると、第2のバッファ層112の結晶性が良くなる。最も好ましくはn型不純物をアンドープのGaNとすると最も結晶性が良い窒化物半導体が得られる。従来のように負電極を形成するn側コンタクト層を数μm以上の膜厚で、高キャリア濃度の単一の窒化物半導体層で構成しようとする、n型不純物濃度の大きい層を成長させる必要がある。不純物濃度の大きい厚膜の層は結晶性が悪くなる傾向にある。このため結晶

性の悪い層の上に、活性層等の他の窒化物半導体を成長させても、結晶欠陥を他の層が引き継ぐことになって結晶性の向上が望めない。そこで、n側コンタクト層12層を成長させる前に、不純物濃度が小さい、結晶性の良い第2のバッファ層112を成長させることにより、キャリア濃度が大きく結晶性の良いn側コンタクト層12を成長させることができる。この第2のバッファ層112の膜厚は、0.1  $\mu\text{m}$ 以上、さらに好ましくは0.5  $\mu\text{m}$ 以上、最も好ましくは1  $\mu\text{m}$ 以上、20  $\mu\text{m}$ 以下に調整することが望ましい。第2のバッファ層112が0.1  $\mu\text{m}$ よりも薄いと、不純物濃度の大きいn型コンタクト層12を厚く成長させなければならず、n側コンタクト層12の結晶性の向上があまり望めない傾向にある。また20  $\mu\text{m}$ よりも厚いと、第2のバッファ層112自体に結晶欠陥が多くなりやすい傾向にある。また第2のバッファ層112を厚く成長させる利点として、放熱性の向上が挙げられる。つまりレーザ素子を作製した場合に、第2のバッファ層112で熱が広がりやすくレーザ素子の寿命が向上する。さらにレーザ光の漏れ光が第2のバッファ層112内で広がって、楕円形に近いレーザ光が得やすくなる。なお、第2のバッファ層112は、基板にGaN、SiC、ZnO等の導電性基板を使用した場合には省略してもよい。

【0051】(n側コンタクト層12) n側コンタクト層12は負電極を形成するコンタクト層として作用する層であり、0.2  $\mu\text{m}$ 以上、4  $\mu\text{m}$ 以下に調整することが望ましい。0.2よりも薄いと、後で負電極を形成する際に、この層を露出させるようにエッチングレートを制御するのが難しく、一方、4  $\mu\text{m}$ 以上にすると不純物の影響で結晶性が悪くなる傾向にある。このn側コンタクト層12の窒化物半導体にドーピングするn型不純物の範囲は $1 \times 10^{17} / \text{cm}^3 \sim 1 \times 10^{21} / \text{cm}^3$ の範囲、さらに好ましくは、 $1 \times 10^{18} / \text{cm}^3 \sim 1 \times 10^{19} / \text{cm}^3$ に調整することが望ましい。 $1 \times 10^{17} / \text{cm}^3$ よりも小さいとn電極の材料と好ましいオーミックが得られにくくなるので、レーザ素子では閾値電流、電圧の低下が望めず、 $1 \times 10^{21} / \text{cm}^3$ よりも大きいと、素子自体のリーク電流が多くなったり、また結晶性も悪くなるため、素子の寿命が短くなる傾向にある。なおn側コンタクト層12においては、n電極23とのオーミック接触抵抗を小さくするために、該n側コンタクト層12のキャリア濃度を上げる不純物の濃度を、nクラッド層14よりも大きくすることが望ましい。なお、n側コンタクト層12は基板にGaN、SiC、ZnO等の導電性基板を使用し基板裏面側に負電極を設ける場合にはコンタクト層としてではなくバッファ層として作用する。

【0052】また、第2のバッファ層11、及びn側コンタクト層12の内の少なくとも一方の層を、超格子層とすることもできる。超格子層とすると、この層の結晶

性が飛躍的に良くなり、閾値電流が低下する。好ましくは第2のバッファ層11よりも膜厚が薄いn側コンタクト層12の方を超格子層とする。n側コンタクト層12を互いにバンドギャップエネルギーが異なる第1の層と第2の層とが積層されてなる超格子構造とした場合においては、好ましくはバンドギャップエネルギーの小さな層を露出させてn電極23を形成することにより、n電極23との接触抵抗が低くでき閾値を低下させることができる。なおn型窒化物半導体と好ましいオーミックが得られるn電極23の材料としてはAl、Ti、W、Si、Zn、Sn、In等の金属若しくは合金が挙げられる。

【0053】また、n型コンタクト層12を不純物濃度が異なる超格子層とすることにより、実施形態1において説明したHEMTに類似した効果により横方向の抵抗値を低くでき、LD素子の閾値電圧、電流を低くすることができる。

【0054】(クラック防止層13) クラック防止層13は、例えば、Siを $5 \times 10^{18} / \text{cm}^3$ ドーピングしたIn<sub>0.1</sub>Ga<sub>0.9</sub>Nからなり、例えば、500オングストロームの膜厚を有する。このクラック防止層13はInを含むn型の窒化物半導体、好ましくはInGaNを成長させて形成することにより、その上に形成されるAlを含む窒化物半導体層中にクラックが入るのを防止することができる。なお、このクラック防止層13は100オングストローム以上、0.5  $\mu\text{m}$ 以下の膜厚で成長させることが好ましい。100オングストロームよりも薄いと前記のようにクラック防止として作用しにくく、0.5  $\mu\text{m}$ よりも厚いと、結晶自体が黒変する傾向にある。なお、このクラック防止層13は、本実施形態1のようにn側コンタクト層12を超格子とする場合、または次に成長させるn側クラッド層14を超格子層とする場合には省略してもよい。

【0055】(n型超格子からなるn側クラッド層14) n側クラッド層は、例えばSiを $5 \times 10^{18} / \text{cm}^3$ ドーピングしたn型Al<sub>0.2</sub>Ga<sub>0.8</sub>Nからなり、20オングストロームの膜厚を有する第1の層、及びアンドープのGaNよりなり、20オングストロームの膜厚を有する第2の層とが交互に積層された超格子層よりなり、全体で例えば0.5  $\mu\text{m}$ の膜厚を有する。このn型クラッド層14はキャリア閉じ込め層、及び光閉じ込め層として作用し、超格子層とした場合にはいずれか一方の層をAlを含む窒化物半導体、好ましくはAlGaNを成長させることが望ましく、100オングストローム以上、2  $\mu\text{m}$ 以下、さらに好ましくは500オングストローム以上、1  $\mu\text{m}$ 以下で成長させることにより良好なキャリア閉じ込め層が成長できる。このn型クラッド層14は単一の窒化物半導体で成長させることもできるが、超格子層とすることがクラックのない結晶性のよいキャリア閉じ込め層が形成できる。



【0056】(n側光ガイド層15) n側光ガイド層15は、例えば、Siを $5 \times 10^{18} / \text{cm}^3$  ドープしたn型Ga<sub>0.8</sub>Nからなり、0.1 μmの膜厚を有する。このn側光ガイド層6は、活性層の光ガイド層として作用し、Ga<sub>0.8</sub>N、InGa<sub>0.2</sub>Nを成長させて形成することが望ましく、通常100オングストローム～5 μm、さらに好ましくは200オングストローム～1 μmの膜厚で成長させることが望ましい。なお、この光ガイド層15も超格子層にすることができる。n側光ガイド層15、n側クラッド層14を超格子層にする場合、超格子層を構成する窒化物半導体層の平均的なバンドギャップエネルギーは活性層よりも大きくする。超格子層とする場合には、第1の層及び第2の層の少なくとも一方にn型不純物をドープしてもよいし、またアンドープでも良い。また、この光ガイド層15は、アンドープの窒化物半導体単独若しくはアンドープの窒化物半導体が積層された超格子でもよい。

【0057】(活性層16) 活性層16は、例えば、Siを $8 \times 10^{18} / \text{cm}^3$  でドープしたIn<sub>0.05</sub>Ga<sub>0.95</sub>Nよりなり、25オングストロームの膜厚を有する井戸層と、Siを $8 \times 10^{18} / \text{cm}^3$  ドープしたIn<sub>0.05</sub>Ga<sub>0.95</sub>Nよりなり、50オングストロームの膜厚を有する障壁層とを交互に積層することにより、所定の膜厚を有する多重量子井戸構造(MQW)で構成する。活性層16においては、井戸層、障壁層両方に不純物をドープしても良く、いずれか一方にドープしてもよい。なおn型不純物をドープすると閾値が低下する傾向にある。また、このように活性層16を多重量子井戸構造とする場合には必ずバンドギャップエネルギーの小さい井戸層と、井戸層よりもバンドギャップエネルギーが小さい障壁層とを積層するため、超格子層とは区別される。井戸層の厚さは、100オングストローム以下、好ましくは70オングストローム以下、最も好ましくは、50オングストローム以下にする。障壁層の厚さは150オングストローム以下、好ましくは100オングストローム以下、最も好ましくは70オングストローム以下にする。

【0058】(p側キャップ層17) p側キャップ層17は、活性層16よりもバンドギャップエネルギーが大きい、例えば、Mgを $1 \times 10^{20} / \text{cm}^3$  ドープしたp型Al<sub>0.3</sub>Ga<sub>0.7</sub>Nよりなり、例えば、200オングストロームの膜厚を有する。本実施形態2では、このように、キャップ層17を用いることが好ましいが、このキャップ層は、薄い膜厚に形成されるので、本発明では、n型不純物をドープしてキャリアが補償されたi型としても良い。p側キャップ層17の膜厚は0.1 μm以下、さらに好ましくは500オングストローム以下、最も好ましくは300オングストローム以下に調整する。0.1 μmより厚い膜厚で成長させると、p側キャップ層17中にクラックが入りやすくなり、結晶性

の良い窒化物半導体層が成長しにくいからである。また、p側キャップ層17の膜厚が、0.1 μm以上であると、キャリアがこのエネルギーバリアとなるp型キャップ層17をトンネル効果により通過できなくなるからであり、該トンネル効果によるキャリアの通過を考慮すると、上述したように500オングストローム以下、さらには300オングストローム以下に設定することが好ましい。

【0059】また、p側キャップ層17には、LD素子を発振しやすくするために、Alの組成比が大きいAlGa<sub>0.8</sub>Nを用いて形成することが好ましく、該AlGa<sub>0.8</sub>Nを薄く形成する程、LD素子は発振しやすくなる。例えば、Y値が0.2以上のAl<sub>Y</sub>Ga<sub>1-Y</sub>Nであれば500オングストローム以下に調整することが望ましい。p側キャップ層17の膜厚の下限は特に限定しないが、10オングストローム以上の膜厚で形成することが望ましい。

【0060】(p側光ガイド層18) p側光ガイド層18は、バンドギャップエネルギーがp側キャップ層17よりも小さい、例えば、Mgを $1 \times 10^{20} / \text{cm}^3$  ドープしたp型Ga<sub>0.8</sub>Nよりなり、0.1 μmの膜厚を有する。このp側光ガイド層18は、活性層16の光ガイド層として作用し、n側光ガイド層15と同じくGa<sub>0.8</sub>N、InGa<sub>0.2</sub>Nで成長させて形成することが望ましい。また、この層はp側クラッド層19を成長させる際のバッファ層としても作用し、100オングストローム～5 μm、さらに好ましくは200オングストローム～1 μmの膜厚で成長させることにより、好ましい光ガイド層として作用する。このp側光ガイド層は通常はMg等のp型不純物をドープしてp型の導電型とするが、特に不純物をドープしなくても良い。なお、このp側光ガイド層を超格子層とすることもできる。超格子層とする場合には第1の層及び第2の層の少なくとも一方にp型不純物をドープしてもよいし、またアンドープでも良い。

【0061】(p側クラッド層19=超格子層) p側クラッド層19は、例えば、Mgを $1 \times 10^{20} / \text{cm}^3$  ドープしたp型Al<sub>0.2</sub>Ga<sub>0.8</sub>Nよりなり、例えば、20オングストロームの膜厚を有する第1の層と、例えばMgを $1 \times 10^{20} / \text{cm}^3$  ドープしたp型Ga<sub>0.8</sub>Nよりなり、20オングストロームの膜厚を有する第2の層とが交互に積層された超格子層からなる。このp側クラッド層19は、n側クラッド層14と同じくキャリア閉じ込め層として作用し、特にp型層の抵抗率を低下させるための層として作用する。このp側クラッド層19の膜厚も特に限定しないが、100オングストローム以上、2 μm以下、さらに好ましくは500オングストローム以上、1 μm以下で形成することが望ましい。

【0062】(p側コンタクト層20) p側コンタクト層20は、p側クラッド層19の上に、例えば、Mgを $2 \times 10^{20} / \text{cm}^3$  ドープしたp型Ga<sub>0.8</sub>Nよりなり、

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例えば、150オングストロームの膜厚を有する。このp側コンタクト層20はp型の $\text{In}_x\text{Al}_y\text{Ga}_{1-x-y}\text{N}$  ( $0 \leq x$ ,  $0 \leq y$ ,  $x+y \leq 1$ ) で構成することができ、好ましくは、上述のようにMgをドーブしたGaNとすれば、p電極21と最も好ましいオーミック接触が得られる。さらにp側コンタクト層の膜厚を500オングストローム以下、さらに好ましくは300オングストローム以下、最も好ましくは200オングストローム以下に調整することが望ましい。なぜなら、上述したように抵抗率が数 $\Omega \cdot \text{cm}$ 以上もあるp型窒化物半導体層の膜厚を500オングストローム以下に調整することにより、さらに抵抗率を下げることができるため、閾値での電流、電圧が低下する。またp型層から除去される水素の量を多くすることができ、さらに抵抗率を低下させることができる。

【0063】なお、本発明では、p側コンタクト層20も超格子層とすることもできる。超格子層とする場合には、特にバンドギャップエネルギーが異なる第1の層と第2の層とを積層し、第1+第2+第1+第2+...というように積層していき、最後にバンドギャップエネルギーが小さい方の層が露出するようにすると、p電極21と好ましいオーミック接触が得られる。p電極21の材料としては、例えばNi、Pd、Ni/Au等を挙げることができる。

【0064】また、本実施形態2では、図2に示すようにp電極21と、n電極23との間に露出した窒化物半導体層の表面に $\text{SiO}_2$ よりなる絶縁膜25が形成され、この絶縁膜25に形成された開口部を介してp電極21と電氣的に接続されたpパッド電極22、及びn電極23と接続されたnパッド電極24が形成される。このpパッド電極22は実質的なp電極21の表面積を広げて、p電極側をワイヤーボンディング、ダイボンディングできるようにし、一方nパッド電極24はn電極23の剥がれを防止する。

【0065】以上の実施形態2の窒化物半導体素子は、第1の層、及び第2の層を弾性歪み限界以下の膜厚にして積層された超格子層である、結晶性のよいp型クラッド層19を備えている。これによって、本実施形態2の窒化物半導体素子は、p側クラッド層19の抵抗値を、超格子構造を有しないp側クラッド層に比較して1桁以上低くすることができるので、閾値電圧、電流を低くすることができる。

【0066】また、本実施形態2の窒化物半導体素子ではp型 $\text{Al}_y\text{Ga}_{1-y}\text{N}$ を含むp側クラッド層19に接して、バンドギャップエネルギーの小さい窒化物半導体をp側コンタクト層20として、その膜厚を500オングストローム以下と薄く形成することにより、実質的にp側コンタクト層20のキャリア濃度が高くなりp電極と好ましいオーミックが得られて、素子の閾値電流、電圧を低くすることができる。さらに、n側コンタクト

層を成長させる前に、第2のバッファ層112を備えているので、第2のバッファ層112の上に成長させる窒化物半導体層の結晶性が良くなり、長寿命の素子を実現できる。好ましくは、第2のバッファ層112の上に成長させるn側コンタクト層を超格子とすると、横方向の抵抗値が低くなり、閾値電圧・閾値電流の低い素子を実現できる。

【0067】なお、本実施形態2のLD素子ではInGaNのような、少なくともインジウムを含む窒化物半導体を活性層16に備える場合には、 $\text{In}_x\text{Ga}_{1-x}\text{N}$ と、 $\text{Al}_y\text{Ga}_{1-y}\text{N}$ とが交互に積層された超格子層を、活性層16を挟設する層(n側クラッド層14及びp側クラッド層19)として用いることが好ましい。これによって、活性層16と該超格子層とのバンドギャップエネルギー差、屈折率差を大きくできるため、該超格子層をレーザ素子を実現する際に非常に優れた光閉じ込め層として動作させることができる。さらにInGaNは結晶の性質が他のAlGaNのようなAlを含む窒化物半導体に比べて柔らかいので、InGaNを活性層とすると、積層した各窒化物半導体層全体にクラックが入りにくくなる。これによって、LD素子の寿命を長くすることができる。

【0068】本実施形態2のように量子井戸構造を有する活性層16を有するダブルヘテロ構造の半導体素子の場合、その活性層16に接して、活性層16よりもバンドギャップエネルギーが大きい膜厚0.1 $\mu\text{m}$ 以下の窒化物半導体よりなるp側キャップ層17、好ましくはAlを含む窒化物半導体よりなるp側キャップ層17を設け、そのp側キャップ層17よりも活性層から離れた位置に、p側キャップ層17よりもバンドギャップエネルギーが小さいp側光ガイド層18を設け、そのp側光ガイド層18よりも活性層から離れた位置に、p側光ガイド層18よりもバンドギャップが大きい窒化物半導体、好ましくはAlを含む窒化物半導体を含む超格子構造を有するp側クラッド層19を設けることは非常に好ましい。しかもp側キャップ層17のバンドギャップエネルギーを大きくしてあるため、n層から注入された電子が、このp側キャップ層17で阻止されて閉じ込められ、電子が活性層をオーバーフローしないために、素子のリーク電流が少なくなる。

【0069】以上の実施形態2の窒化物半導体素子では、レーザ素子の構造として好ましい構造を示したが、本発明ではn型の超格子層は活性層16から下のn型窒化物半導体層領域(n型層側)に少なくとも1層有していれば良く、またp型の超格子層も活性層16から上のp型窒化物半導体層領域(p型層側)に少なくとも1層有していれば良く、素子構成は特に規定するものではない。但し、前記超格子層はp層側に形成する場合はキャリア閉じ込め層としてのp側クラッド層19に形成し、n層側に形成する場合はn電極23が接した電流注入層

としてのnコンタクト層12、またはキャリア閉じ込めとしてのnクラッド層14として形成することが素子のV<sub>f</sub>、閾値を低下させる上で最も好ましい傾向にある。また、実施形態2の素子と同様の構成を、LED素子に適用できることはいうまでもない（ただし、LED素子では、リッジ部は必要ない）。

【0070】以上のように構成された実施形態2の窒化物半導体素子では、各層が形成された後、Hを含まない雰囲気、例えば、窒素雰囲気中で、400℃以上、例えば700℃でアニーリングを行うことが好ましく、これによって、p型窒化物半導体層領域の各層をさらに低抵抗化することができるので、これによって、さらに閾値電圧を低くすることができる。

【0071】また、実施形態2の窒化物半導体素子では、p側コンタクト層12の表面にNiとAuよりなるp電極21がストライプ状に形成され、このp電極21に対して左右対称にn側コンタクト層を露出させて、そのn側コンタクト層表面のほぼ全面にn電極23を設けている。このように、絶縁性基板を用いた場合p電極21の両側に左右対称にn電極23を設ける構造は、閾値電圧を低くする上で非常に有利である。

【0072】なお、本実施形態2では、リッジ部（ストライプ状の電極）に垂直な方向で劈開した劈開面（共振器面）にSiO<sub>2</sub>とTiO<sub>2</sub>よりなる誘電体多層膜を形成してもよい。

【0073】このように、本発明において、超格子層は、活性層を挟設するn型領域又はp型領域に形成されるキャリア閉じ込め層としてのクラッド層、活性層の光ガイド層、若しくは電極が接して形成される電流注入層として用いられるため、超格子層を構成する窒化物半導体の平均バンドギャップエネルギーが活性層よりも大きくなるように調整することが望ましい。

【0074】

【実施例】以下、実施例において本発明を詳説する。

〔実施例1〕本発明に係る実施例1は図2に示す窒化物半導体素子（LED素子）の作成例であり、以下の手順で作製される。まず、サファイア（C面）よりなる基板10を反応容器内にセットし、容器内を水素で十分置換した後、水素を流しながら、基板の温度を1050℃まで上昇させ、基板のクリーニングを行う。続いて、温度を510℃まで下げ、キャリアガスに水素、原料ガスにアンモニア（NH<sub>3</sub>）とTMG（トリメチルガリウム）とを用い、基板10上にGaNよりなる第1のバッファ層11を約200オングストロームの膜厚で成長させる。

【0075】バッファ層11成長後、TMGのみ止めて、温度を1050℃まで上昇させる。1050℃になったら、同じく原料ガスにTMG、アンモニアガスを用い、キャリア濃度 $1 \times 10^{18} / \text{cm}^3$ のアンドープGaNよりなる第2のバッファ層112を5μmの膜厚で成長させる。第2のバッファ層はIn<sub>x</sub>Al<sub>1-y</sub>Ga<sub>1-x-y</sub>

-y N（0≤X、0≤Y、X+Y≤1）で構成でき、その組成は特に問うものではないが、好ましくはアンドープでAl（Y値）が0.1以下のAl<sub>y</sub>Ga<sub>1-y</sub>N、最も好ましくはアンドープのGaNとする。続いて、1050℃でTMG、アンモニア、不純物ガスにシランガス（SiH<sub>4</sub>）を用い、Siを $1 \times 10^{19} / \text{cm}^3$ ドープしたn型GaNよりなるn側コンタクト層12を1μmの膜厚で成長させる。このn側コンタクト層12は超格子で形成するとさらに好ましい。

10 【0076】次に、温度を800℃にして、原料ガスにTMG、TMI（トリメチルインジウム）、アンモニア、不純物ガスにシランガスを用い、Siを $5 \times 10^{18} / \text{cm}^3$ ドープしたIn<sub>0.1</sub>Ga<sub>0.9</sub>Nよりなるクラック防止層13を500オングストロームの膜厚で成長させる。そして温度を1050℃にして、TMA、TMG、アンモニア、シランガスを用い、Siを $5 \times 10^{18} / \text{cm}^3$ ドープしたn型Al<sub>0.2</sub>Ga<sub>0.8</sub>Nよりなる第1の層を20オングストロームの膜厚で成長させ、続いて、TMA、シランを止め、アンドープGaNよりなる第2の層を20オングストロームの膜厚で成長させる。そして、この操作をそれぞれ100回繰り返し、総膜厚0.4μmの超格子層よりなるn側クラッド層14を成長させる。

20 【0077】続いて、1050℃でSiを $5 \times 10^{18} / \text{cm}^3$ ドープしたn型GaNよりなるn側光ガイド層15を0.1μmの膜厚で成長させる。次に、TMG、TMI、アンモニア、シランを用いて活性層16を成長させる。活性層16は温度を800℃に保持して、まずSiを $8 \times 10^{18} / \text{cm}^3$ でドープしたIn<sub>0.2</sub>Ga<sub>0.8</sub>Nよりなる井戸層を25オングストロームの膜厚で成長させる。次にTMIのモル比を変化させるのみで同一温度で、Siを $8 \times 10^{18} / \text{cm}^3$ ドープしたIn<sub>0.01</sub>Ga<sub>0.99</sub>Nよりなる障壁層を50オングストロームの膜厚で成長させる。この操作を2回繰り返し、最後に井戸層を積層した総膜厚175オングストロームの多重量子井戸構造（MQW）の活性層16を成長させる。

40 【0078】次に、温度を1050℃に上げ、原料ガスにTMG、TMA、アンモニア、不純物ガスにCp<sub>2</sub>Mg（シクロペンタジエニルマグネシウム）を用い、活性層よりもバンドギャップエネルギーが大きく、Mgを $1 \times 10^{20} / \text{cm}^3$ ドープしたp型Al<sub>0.3</sub>Ga<sub>0.7</sub>Nよりなるp側キャップ層17を300オングストロームの膜厚で成長させる。続いて、1050℃で、バンドギャップエネルギーがp側キャップ層17よりも小さい、Mgを $1 \times 10^{20} / \text{cm}^3$ ドープしたp型GaNよりなるp側光ガイド層18を0.1μmの膜厚で成長させる。

50 【0079】続いて、TMA、TMG、アンモニア、Cp<sub>2</sub>Mgを用い、1050℃でMgを $1 \times 10^{20} / \text{cm}^3$

<sup>3</sup> ドープしたp型Al<sub>0.2</sub>Ga<sub>0.8</sub>Nよりなる第1の層を20オングストロームの膜厚で成長させ、続いてTMAのみを止め、Mgを $1 \times 10^{20} / \text{cm}^3$  ドープしたp型GaNよりなる第2の層を20オングストロームの膜厚で成長させる。そしてこの操作をそれぞれ100回繰り返し、総膜厚0.4 μmの超格子層よりなるp側クラッド層19を形成する。最後に、1050℃で、p側クラッド層19の上に、Mgを $2 \times 10^{20} / \text{cm}^3$  ドープしたp型GaNよりなるp側コンタクト層20を150オングストロームの膜厚で成長させる。

【0080】反応終了後、温度を室温まで下げ、さらに窒素雰囲気中、ウェーハを反応容器内において、700℃でアニーリングを行い、p型層をさらに低抵抗化する。アニーリング後、ウェーハを反応容器から取り出し、図2に示すように、RIE装置により最上層のp側コンタクト層20と、p側クラッド層19とをエッチングして、4 μmのストライプ幅を有するリッジ形状とする。

【0081】次にリッジ表面にマスクを形成し、図2に示すように、ストライプ状のリッジに対して左右対称にして、n側コンタクト層12の表面を露出させる。次にp側コンタクト層20のストライブリッジ最表面のほぼ全面にNiとAuよりなるp電極21を形成する。一方、TiとAlよりなるn電極23をストライプ状のn側コンタクト層3のほぼ全面に形成する。

【0082】次に、図2に示すようにp電極21と、n電極23との間に露出した窒化物半導体層の表面にSiO<sub>2</sub>よりなる絶縁膜25を形成し、この絶縁膜25を介してp電極21と電氣的に接続したpパッド電極22、及びnパッド電極24を形成する。以上のようにして、n電極とp電極とを形成したウェーハを研磨装置に移送

し、ダイヤモンド研磨剤を用いて、窒化物半導体を形成していない側のサファイア基板1をラッピングし、基板の厚さを50 μmとする。ラッピング後、さらに細かい研磨剤で1 μmポリシングして基板表面を鏡面状とする。

【0083】基板研磨後、研磨面側をスクライブして、ストライプ状の電極に垂直な方向でバー状に劈開し、劈開面に共振器を作製する。共振器面にSiO<sub>2</sub>とTiO<sub>2</sub>よりなる誘電体多層膜を形成し、最後にp電極に平行な方向で、バーを切断してレーザチップとした。次にチップをフェースアップ（基板とヒートシンクとが対向した状態）でヒートシンクに設置し、それぞれの電極をワイヤーボンディングして、室温でレーザ発振を試みたところ、室温において、閾値電流密度 $2.9 \text{ kA} / \text{cm}^2$ 、閾値電圧4.4 Vで、発振波長405 nmの連続発振が確認され、50時間以上の寿命を示した。

【0084】（比較例1）一方、第2のバッファ層112を成長させず、さらにn側コンタクト層12をSiを $1 \times 10^{19} / \text{cm}^3$  ドープしたn型GaN単一で5 μm成長させ、n側クラッド層14をSiを $1 \times 10^{19} / \text{cm}^3$  ドープしたn型Al<sub>0.2</sub>Ga<sub>0.8</sub>N単一で0.4 μm成長させ、p側クラッド層19をMgを $1 \times 10^{20} / \text{cm}^3$  ドープしたp型Al<sub>0.2</sub>Ga<sub>0.8</sub>N単一で0.4 μm成長させ、さらにp側コンタクト層20をMgを $2 \times 10^{20} / \text{cm}^3$  ドープした単一のp型GaNを0.2 μm成長させる他は実施例1と同様にしてレーザ素子を得た。つまり基本構成として、表1に示すように構成する。

【0085】

【表1】

基板	10・・・サファイア	
バッファ層	11・・・GaN	200Å
nコンタクト層	12・・・Siドープn型GaN Si: $1 \times 10^{19} / \text{cm}^3$	5 $\mu\text{m}$
クラック防止層	13・・・Siドープn型In <sub>0.1</sub> Ga <sub>0.9</sub> N Si: $5 \times 10^{18} / \text{cm}^3$	500Å
nクラッド層	14・・・Siドープn型Al <sub>0.2</sub> Ga <sub>0.8</sub> N Si: $5 \times 10^{18} / \text{cm}^3$	0.5 $\mu\text{m}$
n光ガイド層	15・・・Siドープn型GaN Si: $5 \times 10^{18} / \text{cm}^3$	0.1 $\mu\text{m}$
活性層(MQW)	16・・・SiドープIn <sub>0.2</sub> Ga <sub>0.8</sub> N	25Å
	(総膜厚175Å) SiドープIn <sub>0.01</sub> Ga <sub>0.99</sub> N Si: $8 \times 10^{18} / \text{cm}^3$	50Å
キャップ層	17・・・Mgドープp型Al <sub>0.1</sub> Ga <sub>0.9</sub> N Mg: $1 \times 10^{20} / \text{cm}^3$	300Å
p光ガイド層	18・・・Mgドープp型GaN Mg: $1 \times 10^{20} / \text{cm}^3$	0.1 $\mu\text{m}$
pクラッド層	19・・・Mgドープp型Al <sub>0.2</sub> Ga <sub>0.8</sub> N Mg: $1 \times 10^{20} / \text{cm}^3$	0.5 $\mu\text{m}$
pコンタクト層	20・・・Mgドープp型GaN Mg: $2 \times 10^{20} / \text{cm}^3$	0.2 $\mu\text{m}$

【0086】このように構成した比較例のレーザ素子は、閾値電流密度  $7 \text{ kA} / \text{cm}^2$  で連続発振が確認されたが、閾値電圧は8.0V以上あり、数分で切れてしまった。

【0087】[実施例2] 実施例1において、n側コンタクト層12を、Siを  $2 \times 10^{19} / \text{cm}^3$  ドープしたn型Al<sub>0.05</sub>Ga<sub>0.95</sub>Nよりなる第1の層を30オングストロームの膜厚で成長させ、続いて、アンドープのGaNよりなる第2の層を30オングストロームの膜厚で成長させて、これを繰り返し、総膜厚1.2  $\mu\text{m}$ の超格子構造とする。それ以外の構造は実施例1と同様の構造を有するレーザ素子としたところ、閾値電流密度  $2.7 \text{ kA} / \text{cm}^2$ 、閾値電圧4.2Vで、寿命も60時間以上を示した。

【0088】[実施例3] 実施例2において、n側コンタクト層12を構成する超格子において、第2の層をSiを  $1 \times 10^{18} / \text{cm}^3$  ドープしたGaNとする他は、実施例2と同様の構造を有するレーザ素子を作製したところ、実施例2とほぼ同等の特性を有するレーザ素子が得られた。

【0089】[実施例4] 実施例1において、第2のバッファ層112を、Siを  $1 \times 10^{17} / \text{cm}^3$  ドープしたGaNとして、4  $\mu\text{m}$ 成長させる他は、実施例1と同様の構造を有するレーザ素子を作製したところ、閾値電流密度  $2.9 \text{ kA} / \text{cm}^2$ 、閾値電圧4.5Vに上昇したが、寿命は50時間以上を示した。

【0090】[実施例5] 実施例1において、n側コンタクト層12を、Siを  $2 \times 10^{19} / \text{cm}^3$  ドープしたn型Al<sub>0.2</sub>Ga<sub>0.8</sub>Nよりなる第1の層を60オングストロームの膜厚で成長させ、続いて、Siを  $1 \times$

$10^{19} / \text{cm}^3$  ドープしたGaNよりなる第2の層を40オングストロームの膜厚で成長させて、順次これを繰り返し、総膜厚2  $\mu\text{m}$ の超格子構造とする。そして、n側クラッド層14をSiを  $1 \times 10^{19} / \text{cm}^3$  ドープしたn型Al<sub>0.2</sub>Ga<sub>0.8</sub>N単一で0.4  $\mu\text{m}$ 成長させる。それ以外の構造は実施例1と同様の構造を有するレーザ素子としたところ、閾値電流密度  $3.2 \text{ kA} / \text{cm}^2$ 、閾値電圧4.8Vで、寿命も30時間以上を示した。

【0091】[実施例6] 実施例6は、実施例1と比較して、以下の(1)、(2)が異なる他は、実施例1と同様に構成される。

(1) バッファ層11成長後、TMGのみ止めて、温度を1050℃まで上昇させる。1050℃になったら、原料ガスにTMA、TMG、アンモニア、シランを用い、Siを  $1 \times 10^{19} / \text{cm}^3$  ドープしたn型Al<sub>0.2</sub>Ga<sub>0.8</sub>Nよりなる第1の層を60オングストロームの膜厚で成長させ、続いて、シラン、TMAを止めアンドープのGaNよりなる第2の層を40オングストロームの膜厚で成長させる。そして第1層+第2層+第1層+第2層+・・・というように超格子層を構成し、それぞれ第1の層を500層、第2の層を500層交互に積層し、総膜厚5  $\mu\text{m}$ の超格子よりなるn側コンタクト層12を形成する。

(2) 次に、実施例1と同様にして、Siを  $5 \times 10^{18} / \text{cm}^3$  ドープしたIn<sub>0.1</sub>Ga<sub>0.9</sub>Nよりなるクラック防止層13を500オングストロームの膜厚で成長させる。そして、温度を1050℃にして、TMA、TMG、アンモニア、シランを用い、Siを  $5 \times 10^{18} / \text{cm}^3$  ドープしたn型Al<sub>0.2</sub>Ga<sub>0.8</sub>Nよ

りなるn側クラッド層14を0.5 $\mu$ mの膜厚で成長させる。後の、n側クラッド層14から上は、実施例1のレーザ素子と同様の構造を有するレーザ素子とする。つまり表1の基本構造において、n側コンタクト層12、及びp側クラッド層19を超格子とし、p側コンタクト層20の膜厚を実施例1のように150オングストロームとするレーザ素子を作製する。このレーザ素子は閾値電流密度3.2kA/cm<sup>2</sup>、閾値電圧4.8Vで、405nmの連続発振が確認され、寿命も30時間以上を示した。

【0092】さらに、実施例6の構造のLD素子のp側コンタクト層の膜厚を順次変更した際、そのp側コンタクト層の膜厚と、LD素子の閾値電圧との関係を図3に示す。これはp側コンタクト層が、左から順にA(10オングストローム以下)、B(10オングストローム)、C(30オングストローム)、D(150オングストローム、本実施例)、E(500オングストローム)、F(0.2 $\mu$ m)、G(0.5 $\mu$ m)、H(0.8 $\mu$ m)の場合の閾値電圧を示している。この図に示すように、p側コンタクト層の膜厚が500オングストロームを超えると閾値電圧が次第に上昇する傾向にある。p側コンタクト層20の膜厚は500オングストローム以下、さらに好ましくは300オングストローム以下であることが望ましい。なお10オングストローム以下(およそ1原子層、2原子層近く)になると、下部のp側クラッド層19の表面が露出してくるため、p電極のコンタクト抵抗が悪くなり、閾値電圧は上昇する傾向にある。しかしながら、本発明のLD素子では超格子層を有しているために、閾値電圧が比較例のものに比べて大幅に低下している。

【0093】(比較例2)表1の構成のレーザ素子において、n側クラッド層14をSiを $1 \times 10^{19}$ /cm<sup>3</sup>ドープしたn型Al<sub>0.2</sub>Ga<sub>0.8</sub>Nよりなる第1の層を180オングストロームの膜厚で成長させ、続いてアンドープのGaNよりなる第2の層を120オングストロームの膜厚で成長させ、総膜厚0.6 $\mu$ mの多層膜とする。つまり第1の層と第2の層の膜厚を厚くした構造で構成してレーザ素子を作製したところ、閾値電流密度6.5kA/cm<sup>2</sup>で連続発振が確認され、閾値電圧が7.5Vであった。なおこのレーザ素子は数分で切れてしまった。

【0094】[実施例7]実施例6において、p側クラッド層19をMgを $1 \times 10^{20}$ /cm<sup>3</sup>ドープしたAl<sub>0.2</sub>Ga<sub>0.8</sub>N、60オングストロームよりなる第1の層と、Mgを $1 \times 10^{20}$ /cm<sup>3</sup>ドープしたp型GaN、40オングストロームよりなる第2の層とを積層した総膜厚0.5 $\mu$ mの超格子構造とする他は実施例6と同様のレーザ素子を作製する。つまり、実施例6のp側クラッド層19を構成する超格子層の膜厚を変える他は同様にしてレーザ素子を作製したところ、閾値電圧が

実施例6のレーザ素子に比較して若干上昇する傾向にあったが、20時間以上の寿命を示した。

【0095】[実施例8]実施例7において、さらにn側クラッド層14をSiを $1 \times 10^{19}$ /cm<sup>3</sup>ドープしたn型Al<sub>0.2</sub>Ga<sub>0.8</sub>N、60オングストロームよりなる第1の層と、Siを $1 \times 10^{19}$ /cm<sup>3</sup>ドープしたn型GaN、40オングストロームよりなる第2の層とを積層した総膜厚0.5 $\mu$ mの超格子構造とする他は実施例7と同様のレーザ素子を作製する。つまり、実施例6のn側コンタクト層12、p側クラッド層19に加えてn側クラッド層を超格子としたレーザ素子は、実施例6とほぼ同等の特性を有していた。

【0096】[実施例9]実施例1において、第2のバッファ層112を成長させずに、表1に示すように、第1のバッファ層11の上に、直接n側コンタクト層12としてSiを $1 \times 10^{19}$ /cm<sup>3</sup>ドープしたn型GaN層を5 $\mu$ m成長させる。その他は、実施例1と同様の構造を有するレーザ素子とする。つまり、表1の基本構造において、n側クラッド層14を20オングストロームのSi( $1 \times 10^{19}$ /cm<sup>3</sup>)ドープn型Al<sub>0.2</sub>Ga<sub>0.8</sub>Nよりなる第1の層と、20オングストロームのアンドープGaNよりなる第2の層とを積層してなる総膜厚0.4 $\mu$ mの超格子構造とする。さらにp側クラッド層19を20オングストロームのMg( $1 \times 10^{20}$ /cm<sup>3</sup>)ドープp型Al<sub>0.2</sub>Ga<sub>0.8</sub>Nよりなる第1の層と、20オングストロームのMg( $1 \times 10^{20}$ /cm<sup>3</sup>)ドープp型GaNよりなる第2の層とを積層してなる総膜厚0.4 $\mu$ mの超格子構造とする。さらにまたp側コンタクト層20を実施例1のように150オングストロームのMg( $2 \times 10^{20}$ /cm<sup>3</sup>)ドープp型GaNとしたところ、閾値電流密度3.3kA/cm<sup>2</sup>で、405nmの連続発振が確認され、閾値電圧は5.0V、寿命も30時間以上を示した。

【0097】[実施例10]実施例9において、n側クラッド層14の超格子を構成する第2の層を、Siを $1 \times 10^{17}$ /cm<sup>3</sup>ドープしたGaNとする他は、実施例9と同様のレーザ素子を作製する。つまりバンドギャップエネルギーの大きい方の層に、Siを多くドープする他は、実施例9と同様にして作製したレーザ素子は、実施例9とほぼ同等の特性を示した。

【0098】[実施例11]実施例9において、n側クラッド層14を構成する第2の層を、Siを $1 \times 10^{19}$ /cm<sup>3</sup>ドープしたn型In<sub>0.01</sub>Ga<sub>0.99</sub>Nとする他は同様にしてレーザ素子を作製する。つまりn側クラッド層14の超格子を構成する第2の層の組成をInGaNとし、第1の層と第2の層との不純物濃度を同じにする他は、実施例9と同様にして作製したレーザ素子は、実施例9とほぼ同等の特性を示した。

【0099】[実施例12]実施例9において、n側クラッド層14を構成する第1の層(Si: $1 \times 10^{19}$



／ $\text{cm}^3$  ドープ  $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$  の膜厚を60オングストロームとし、第2の層を  $\text{Si}$  を  $1 \times 10^{19}$  ／ $\text{cm}^3$  ドープした40オングストロームの  $\text{GaN}$  とし、総膜厚0.5  $\mu\text{m}$  の超格子構造とする。さらにp側クラッド層19を構成する第1の層 ( $\text{Mg}$  :  $1 \times 10^{20}$  ／ $\text{cm}^3$  ドープ  $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ ) の膜厚を60オングストロームとし、第2の層 ( $\text{Mg}$  :  $1 \times 10^{20}$  ／ $\text{cm}^3$  ドープ  $\text{GaN}$ ) の膜厚を40オングストロームとし、総膜厚0.5  $\mu\text{m}$  の超格子構造とする。つまりn側クラッド層14を構成する第1の層と第2の層のドーパ量を同じにして、膜厚を変化させ、p側クラッド層19を構成する第1の層と第2の層との膜厚を変化させる他は、実施例9と同様にしてレーザ素子を作製したところ、閾値電流密度3.4  $\text{kA}/\text{cm}^2$  で、405 nmの連続発振が確認され、閾値電圧は5.2 V、寿命も20時間以上を示した。

【0100】 [実施例13] 実施例11において、n側クラッド層14を構成する第2の層 ( $\text{GaN}$ ) の  $\text{Si}$  濃度を  $1 \times 10^{17}$  ／ $\text{cm}^3$  とする他は実施例11と同様の構造を有するレーザ素子を作製したところ、実施例11

【0101】 [実施例14] 実施例11において、n側クラッド層14を構成する第2の層 ( $\text{GaN}$ ) をアンドープとする他は実施例11と同様の構造を有するレーザ素子を作製したところ、実施例11とほぼ同等の特性を有するレーザ素子を作製できた。

【0102】 [実施例15] 実施例9において、n側クラッド層14を  $\text{Si}$  を  $1 \times 10^{19}$  ／ $\text{cm}^3$  ドープしたn型  $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$  単一で0.4  $\mu\text{m}$  成長させる他は同様にしてレーザ素子を作製する。つまり、表1の基本構造において、p側クラッド層19のみを実施例1のように  $\text{Mg}$  を  $1 \times 10^{20}$  ／ $\text{cm}^3$  ドープしたp型  $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$  よりなる第1の層、20オングストロームと、 $\text{Mg}$  を  $1 \times 10^{19}$  ／ $\text{cm}^3$  ドープしたp型  $\text{GaN}$  よりなる第2の層20オングストロームとからなる総膜厚0.4  $\mu\text{m}$  の超格子構造とし、さらに、p側コンタクト層20を実施例1のように150オングストロームの  $\text{Mg}$  ( $2 \times 10^{20}$  ／ $\text{cm}^3$ ) ドープp型  $\text{GaN}$  としたところ、同じく閾値電流密度3.4  $\text{kA}/\text{cm}^2$  で、405 nmの連続発振が確認され、閾値電圧は5.1 V、寿命は20時間以上を示した。

【0103】 [実施例16] 実施例15において、p側クラッド層19を構成する超格子層の膜厚を第1の層 ( $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ ) を60オングストロームとし、第2の層 ( $\text{GaN}$ ) を40オングストロームとして積層し、総膜厚0.5  $\mu\text{m}$  とする他は実施例14と同様のレーザ素子を得たところ、閾値電圧は若干上昇する傾向にあったが、寿命は20時間以上あった。

【0104】 [実施例17] 実施例9において、p側クラッド層19を  $\text{Mg}$  を  $1 \times 10^{20}$  ／ $\text{cm}^3$  ドープしたp

型  $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$  単一で0.4  $\mu\text{m}$  成長させる他は同様にしてレーザ素子を作製する。つまり、表1の基本構造において、n側クラッド層14のみを実施例1のように  $\text{Si}$  を  $1 \times 10^{19}$  ／ $\text{cm}^3$  ドープしたn型  $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$  よりなる第1の層、20オングストロームと、アンドープの  $\text{GaN}$  よりなる第2の層20オングストロームとからなる総膜厚0.4  $\mu\text{m}$  の超格子構造とし、さらに、p側コンタクト層20を実施例1のように150オングストロームの  $\text{Mg}$  ( $2 \times 10^{20}$  ／ $\text{cm}^3$ ) ドープp型  $\text{GaN}$  としたところ、同じく閾値電流密度3.5  $\text{kA}/\text{cm}^2$  で、405 nmの連続発振が確認され、閾値電圧は5.4 V、寿命は10時間以上を示した。

【0105】 [実施例18] 実施例17において、n側クラッド層14を構成する超格子層の膜厚を第1の層 ( $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ ) を70オングストロームとし、第2の層を  $\text{Si}$  を  $1 \times 10^{19}$  ／ $\text{cm}^3$  ドープした  $\text{In}_{0.01}\text{Ga}_{0.99}\text{N}$ 、70オングストロームとして積層し、総膜厚0.49  $\mu\text{m}$  とする他は実施例17と同様のレーザ素子を得たところ、実施例16に比べて閾値電圧が若干上昇する傾向にあったが、同じく10時間以上の寿命を有するレーザ素子を得られた。

【0106】 [実施例19] 実施例17において、n側クラッド層14を構成する超格子層の膜厚を第1の層 ( $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ ) を60オングストロームとし、第2の層 (アンドープ  $\text{GaN}$ ) を40オングストロームとして積層し、総膜厚0.5  $\mu\text{m}$  とする他は実施例16と同様のレーザ素子を得たところ、実施例17に比べて閾値電圧が若干上昇する傾向にあったが、同じく10時間以上の寿命を有するレーザ素子を得られた。

【0107】 [実施例20] 実施例9において、さらにn側光ガイド層15をアンドープの  $\text{GaN}$  よりなる第1の層、20オングストロームと、アンドープの  $\text{In}_{0.1}\text{Ga}_{0.9}\text{N}$  よりなる第2の層、20とを積層してなる総膜厚800オングストロームの超格子層とする。それに加えて、p側光ガイド層18もアンドープの  $\text{GaN}$  よりなる第1の層、20オングストロームと、アンドープの  $\text{In}_{0.1}\text{Ga}_{0.9}\text{N}$  よりなる第2の層、20オングストロームとを積層してなる総膜厚800オングストロームの超格子構造とする。つまり、表1の基本構造において、n側クラッド層14、n側光ガイド層15、p側光ガイド層18、及びp側クラッド層19とを超格子構造とし、さらにまたp側コンタクト層20を実施例1のように150オングストロームの  $\text{Mg}$  ( $2 \times 10^{20}$  ／ $\text{cm}^3$ ) ドープp型  $\text{GaN}$  としたところ、閾値電流密度2.9  $\text{kA}/\text{cm}^2$  で、405 nmの連続発振が確認され、閾値電圧は4.4 V、寿命も60時間以上を示した。

【0108】 [実施例21] 本実施例は図1のLED素子を元に説明する。実施例1と同様にしてサファイアよ

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りなる基板1の上にGa<sub>0.2</sub>Nよりなるバッファ層2を200オングストロームの膜厚で成長させ、次いでSiを $1 \times 10^{19} / \text{cm}^3$  ドープしたn型Ga<sub>0.2</sub>Nよりなるコンタクト層を5μmの膜厚で成長させ、次にIn<sub>0.4</sub>Ga<sub>0.6</sub>Nよりなる膜厚30オングストロームの単一量子井戸構造よりなる活性層4を成長させる。

【0109】(p側超格子層)次に、実施例1と同様にして、Mgを $1 \times 10^{20} / \text{cm}^3$  ドープしたp型Al<sub>0.2</sub>Ga<sub>0.8</sub>Nよりなる第1の層を20オングストロームの膜厚で成長させ、続いてMgを $1 \times 10^{19} / \text{cm}^3$  ドープしたp型Ga<sub>0.2</sub>Nよりなる第2の層を20オングストロームの膜厚で成長させ、総膜厚0.4μmの超格子よりなるp側クラッド層5を成長させる。このp側クラッド層4の膜厚も特に限定しないが、100オングストローム以上、2μm以下、さらに好ましくは500オングストローム以上、1μm以下で成長させることが望ましい。

【0110】次にこのp側クラッド層5の上にMgを $1 \times 10^{20} / \text{cm}^3$  ドープしたp型Ga<sub>0.2</sub>N層を0.5μmの膜厚で成長させる。成長後、ウェーハを反応容器から取り出し実施例1と同様にして、アニーリングを行った後、p側コンタクト層6側からエッチングを行いn電極9を形成すべきn側コンタクト層3の表面を露出させる。最上層のp側コンタクト層6のほぼ全面に膜厚200オングストロームのNi-Auよりなる透光性のp電極7を形成し、その全面電極7の上にAuよりなるpパッド電極8を形成する。露出したn側コンタクト層の表面にもTi-Alよりなるn電極9を形成する。

【0111】以上のようにして電極を形成したウェーハを350μm角のチップに分離してLED素子としたところ、If20mAにおいて520nmの緑色発光を示し、Vfは3.2Vであった。これに対し、p側クラッド層5を単一のMgドープAl<sub>0.2</sub>Ga<sub>0.8</sub>Nで構成したLED素子のVfは3.4Vであった。さらに静電耐圧は本実施例の方が2倍以上の静電耐圧を有していた。

【0112】[実施例22] 実施例21において、p側クラッド層5を構成する超格子層を、第1の層の膜厚を50オングストロームとし、第2の層をMgを $1 \times 10^{20} / \text{cm}^3$  ドープしたGa<sub>0.2</sub>N、50オングストロームとして、それぞれ25層積層し、総膜厚0.25μmの超格子とする他は同様にしてLED素子を作成したところ、実施例21とほぼ同等の特性を有するLED素子が得られた。

【0113】[実施例23] 実施例21において、p側クラッド層5を構成する超格子層の厚さを、第1の層100オングストローム、第2の層を70オングストロームの膜厚として、総膜厚0.25μmの超格子とする他は同様にしてLED素子を作成したところ、Vfは3.4Vであったが、静電耐圧は従来のものよりも20%以

上優れていた。

【0114】[実施例24] 実施例21において、n側コンタクト層3を成長させる際、Siを $2 \times 10^{19} / \text{cm}^3$  ドープしたn型Al<sub>0.2</sub>Ga<sub>0.8</sub>Nよりなる第1の層を60オングストローム、アンドープのGa<sub>0.2</sub>Nよりなる第2の層を40オングストロームの膜厚で成長させ、それぞれ第1の層を500層、第2の層を500層交互に積層し、総膜厚5μmの超格子とする。その他は実施例12と同様にしてLED素子を作製したところ、同じくIf20mAにおいて、Vfは3.1Vに低下し、静電耐圧は従来に比較比較して2.5倍以上に向上した。

【0115】[実施例25] 実施例23において、p側クラッド層5を構成する超格子の第1の層(Al<sub>0.2</sub>Ga<sub>0.8</sub>N)の膜厚を60オングストロームとし、第2の層の膜厚を40オングストロームとして、それぞれ25層交互に積層して、総膜厚0.3μmとする他は同様の構造を有するLED素子を作製したところ、Vfは3.2Vで、静電耐圧は従来の2倍以上であった。

【0116】[実施例26] 本実施例は図4に示すレーザ素子を基に説明する。図4も、図2と同様にレーザ光の共振方向に垂直な方向で素子を切断した際の断面図であるが、図2と異なるところは、基板101にGa<sub>0.2</sub>Nよりなる基板101を用いているところと、第2のバッファ層112を成長させずに、n型不純物をドープした第3のバッファ層113を成長させているところにある。この図4に示すレーザ素子は以下の方法によって得られる。

【0117】まずサファイア基板上にMOVPE法、若しくはHVPE法を用いて、Siを $5 \times 10^{18} / \text{cm}^3$  ドープしたGa<sub>0.2</sub>N層を厚さ300μmで成長させた後、サファイア基板を除去して厚さ300μmのSiドープGa<sub>0.2</sub>N基板101を作製する。Ga<sub>0.2</sub>N基板101は、このように窒化物半導体と異なる基板の上に、例えば100μm以上の膜厚で成長させた後、その異種基板を除去することによって得られる。Ga<sub>0.2</sub>N基板101はアンドープでも良いし、またn型不純物をドープして作製しても良い。n型不純物をドープする場合には通常 $1 \times 10^{17} / \text{cm}^3 \sim 1 \times 10^{19} / \text{cm}^3$  の範囲で不純物をドープすると結晶性の良いGa<sub>0.2</sub>N基板が得られる。

【0118】Ga<sub>0.2</sub>N基板101作製後、温度を1050℃にして、Siを $3 \times 10^{18} / \text{cm}^3$  ドープしたn型Ga<sub>0.2</sub>Nよりなる第3のバッファ層113を3μmの膜厚で成長させる。なお第3のバッファ層113は図1、図2においてn側コンタクト層14に相当する層であるが、電極を形成する層ではないので、ここではコンタクト層とは言わず、第3のバッファ層113という。なおGa<sub>0.2</sub>N基板101と第3のバッファ層113との間に、実施例1と同様にして低温で成長させる第1のバッファ層を成長させても良いが、第1のバッファ層を成長させる場



合には、300オングストローム以下にすることが望ましい。

【0119】次に第3のバッファ層113の上に、実施例1と同様にSiを $5 \times 10^{18} / \text{cm}^3$  ドープしたIn<sub>0.1</sub>Ga<sub>0.9</sub>Nよりなるクラック防止層13を500オングストロームの膜厚で成長させる。次に、Siを $5 \times 10^{18} / \text{cm}^3$  ドープしたn型Al<sub>0.2</sub>Ga<sub>0.8</sub>Nよりなる第1の層、20オングストロームと、Siを $5 \times 10^{18} / \text{cm}^3$  ドープしたGaNよりなる第2の層20オングストロームとを100回交互に積層した、総膜厚0.4μmの超格子層よりなるn側クラッド層14を成長させる。次に実施例1と同様に、Siを $5 \times 10^{18} / \text{cm}^3$  ドープしたn型GaNよりなるn側光ガイド層15を0.1μmの膜厚で成長させる。

【0120】次に、アンドープIn<sub>0.2</sub>Ga<sub>0.8</sub>Nよりなる井戸層、25オングストロームと、アンドープGaNよりなる障壁層50オングストロームとを成長させ、交互に2回繰り返す、最後に井戸層を積層した総膜厚175オングストロームの多重量子井戸構造(MQW)の活性層16を成長させる。

【0121】次に、実施例1と同様に、Mgを $1 \times 10^{20} / \text{cm}^3$  ドープしたp型Al<sub>0.3</sub>Ga<sub>0.7</sub>Nよりなるp側キャップ層17を300オングストロームの膜厚で成長させ、Mgを $1 \times 10^{20} / \text{cm}^3$  ドープしたp型GaNよりなるp側光ガイド層18を0.1μmの膜厚で成長させる。

【0122】次に実施例1と同様に、Mgを $1 \times 10^{20} / \text{cm}^3$  ドープしたp型Al<sub>0.2</sub>Ga<sub>0.8</sub>Nよりなる第1の層、20オングストロームと、Mgを $1 \times 10^{20} / \text{cm}^3$  ドープしたp型GaNよりなる第2の層、20オングストロームよりなる、総膜厚0.4μmの超格子層よりなるp側クラッド層19を形成し、最後に、p側クラッド層19の上に、Mgを $2 \times 10^{20} / \text{cm}^3$  ドープしたp型GaNよりなるp側コンタクト層20を150オングストロームの膜厚で成長させる。

【0123】反応終了後、700℃でアニーリングした後、実施例1と同様に、RIE装置により最上層のp側コンタクト層20と、p側クラッド層19とをエッチングして、4μmのストライプ幅を有するリッジ形状とする。

【0124】次に、実施例1と同じくp側コンタクト層20のストライブリッジ最表面のほぼ全面にNiとAuよりなるp電極21を形成し、GaN基板101の裏面のほぼ全面に、TiとAlよりなるn電極23を形成する。

【0125】次に、図4に示すようにp電極21の面積を除く、p側クラッド層19のSiO<sub>2</sub>よりなる絶縁膜25を形成し、この絶縁膜25を介して、p電極21と電氣的に接続したpパッド電極22を形成する。

【0126】電極形成後、p電極21に垂直な方向でG

aN基板101をバー状に劈開し、劈開面に共振器を製作する。なおGaN基板の劈開面はM面とする。劈開面にSiO<sub>2</sub>とTiO<sub>2</sub>よりなる誘電体多層膜を形成し、最後にp電極に平行な方向で、バーを切断して図4に示すレーザチップとした。次にチップをフェースアップ(基板とヒートシンクとが対向した状態)でヒートシンクに設置し、pパッド電極22をワイヤーボンディングして、室温でレーザ発振を試みたところ、室温において、閾値電流密度 $2.5 \text{ kA} / \text{cm}^2$ 、閾値電圧4.0Vで、発振波長405nmの連続発振が確認され、500時間以上の寿命を示した。これは基板にGaNを使用したことにより、結晶欠陥の広がりが少なくなったことによる。

【0127】

【発明の効果】以上説明したように、本発明に係る窒化物半導体素子は、活性層以外のp型窒化物半導体領域又はn型窒化物半導体領域において、超格子層を用いて構成しているので、電力効率を極めて良くすることができる。すなわち、従来の窒化物半導体素子では、活性層を多重量子井戸構造とすることは提案されていたが、活性層を挟む、例えばクラッド層等は単一の窒化物半導体層で構成されているのが通常であった。しかし、本発明の窒化物半導体素子では量子効果が出現するような層を有する超格子層をクラッド層、若しくは電流を注入するコンタクト層として設けているため、クラッド層側の抵抗率を低くすることができる。これによって、例えばLD素子の閾値電流、閾値電圧を低くでき、該素子を長寿命とすることができる。さらに従来のLEDは静電気に弱かったが、本発明では静電耐圧に強い素子を実現できる。このようにVf、閾値電圧が低くできるので、発熱量も少なくなり、該素子の信頼性も向上させることができる。本発明の窒化物半導体素子によれば、LED、LD等の発光素子はもちろんのこと、窒化物半導体を用いた太陽電池、光センサー、トランジスタ等に利用すると非常の効率の高いデバイスを実現することが可能となりその産業上の利用価値は非常に大きい。

【図面の簡単な説明】

【図1】 本発明に係る実施形態1の窒化物半導体素子(LED素子)の構成を示す模式断面図である。

【図2】 本発明に係る実施形態2の窒化物半導体素子(LD素子)の構成を示す模式断面図である。

【図3】 本発明に係る実施例1のLD素子におけるp側コンタクト層の膜厚と、閾値電圧との関係を示すグラフである。

【図4】 本発明に係る実施例26のLD素子の模式断面図である。

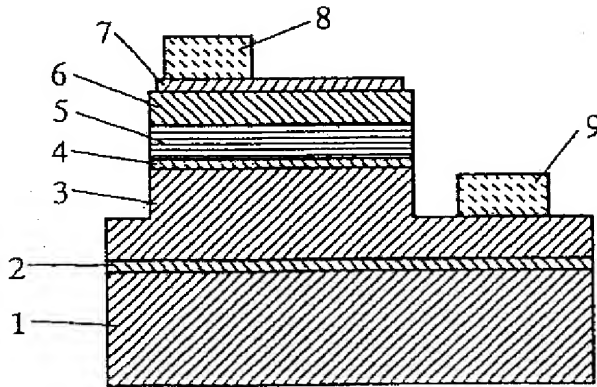
【符号の説明】

- 1、10・・・基板、
- 2、11・・・バッファ層、
- 3、12・・・n側コンタクト層、

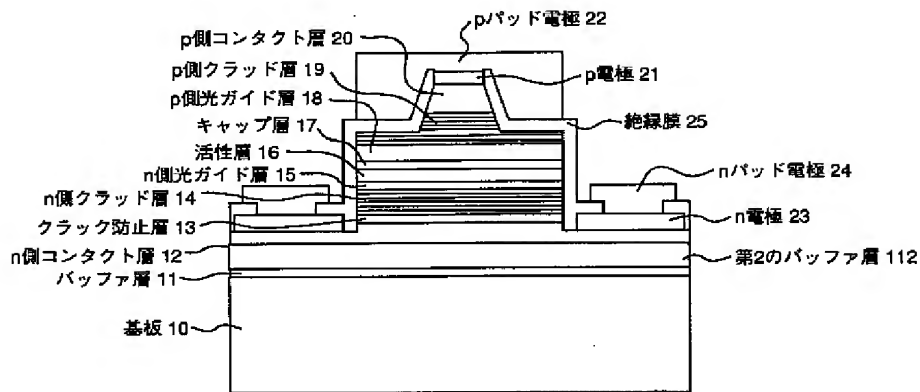
13・・・クラック防止層、  
 14・・・n側クラッド層（超格子層）、  
 15・・・n側光ガイド層、  
 4、16・・・活性層、  
 17・・・キャップ層、  
 18・・・p側光ガイド層、  
 5、19・・・p側クラッド層（超格子層）、  
 6、20・・・p側コンタクト層、

\* 7、21・・・p電極、  
 8、22・・・pパッド電極、  
 9、23・・・n電極、  
 24・・・nパッド電極、  
 25・・・絶縁膜、  
 101・・・GaN基板、  
 112・・・第2のバッファ層、  
 \* 113・・・第3のバッファ層。

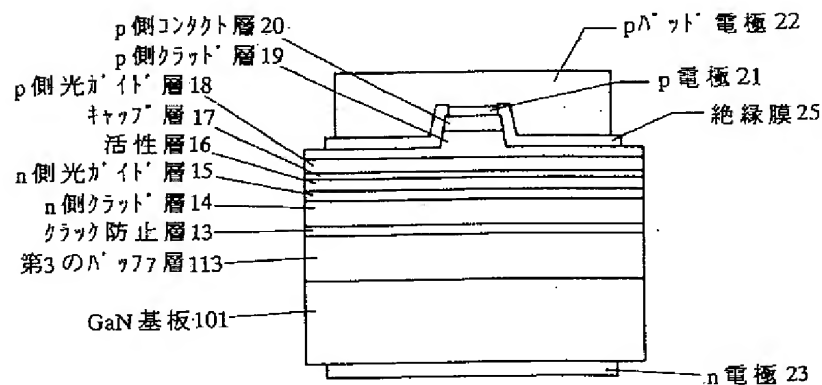
【図1】



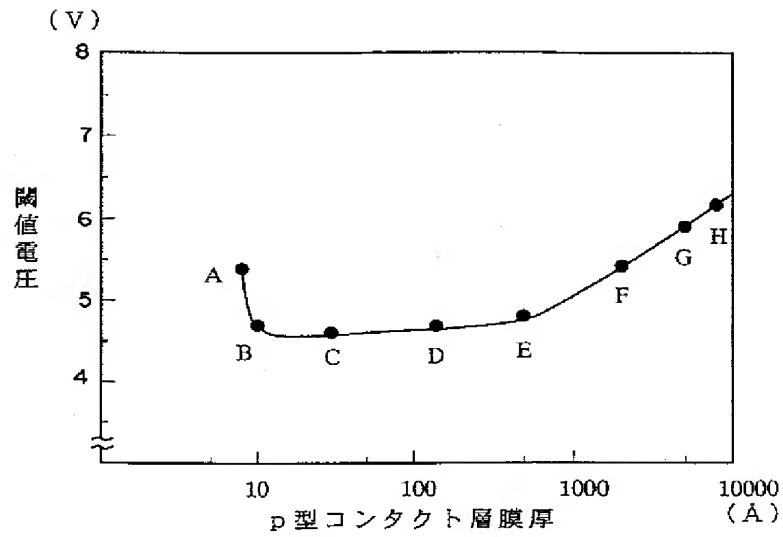
【図2】



【図4】



【図3】



フロントページの続き

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AA77 CA02 CA03 DA05 EA23  
EA28